Chapter 8

Dead Reckoning, Piloting, and Electronic Navigation

Introduction

In this chapter, you will learn how to keep track of the ship's position. It is extremely important that the QMOW be able to quickly estimate the ship's position at any time. Dead reckoning (DR) is one of the most basic and widely used methods of navigating. Dead reckoning is always employed any time a vessel is under way.

The primary reason for using dead reckoning is that the navigator may at any time give a reasonable account of the ship's position without having to take sights or obtain a position from other means. In many places on Earth, a vessel may get beyond the range of today's sophisticated navigational aids and have to rely on methods as old and time tested as the DR. Many vessels have been under way for weeks at a time without having made a landfall or having any other contact with shore and have still come within a very few miles of the desired destination using only a carefully maintained DR plot.

The practice of maintaining a DR plot will be the first task we focus on in this chapter. Piloting will be the second main focus of this chapter. Perhaps you recall from chapter 1 that the QM uses visual aids to establish the ship's position when piloting. Electronic navigation uses several pieces of electronic equipment. State of the art equipment is often used. Currently, the Navy's cutting edge electronic navigation equipment is the WRN-6 Satellite Navigation Set.

Objectives

The material in this chapter will enable you to:

- Identify the primary reason for using dead reckoning, and match plotting instruments and tools with their usages.
- State how you obtain true or magnetic course using the compass rose.
- State the purpose of a course line, and identify the proper method of labeling course lines.
- State the two factors considered when using the dead reckoning process.
- Match the plotting symbols with their appropriate meaning: DR, EP, visual fix, and electronic fix.
- Calculate speed, time, and distance problems using the formula D = S x T, the nautical slide rule, and the 3-minute rule.
- List three methods used to measure a ship's speed through the water,

Topics

The DR Plot

General Information

The importance of maintaining an accurate dead reckoning plot cannot be overemphasized. Since other means of fixing your ship's position may not always be available, a navigator must rely on a DR plot.

If a ship made good the exact course and speed ordered, and there was no wind or current, dead reckoning would, at all times, provide an accurate indication of the ship's position. A navigator must know the position, or approximate position, to determine when to make changes in course and/or speed, to predict the time of sighting lights or other aids to navigation, and to identify landmarks.

Rules

When maintaining a DR plot, there are six rules that govern what actions the QM should take. These rules are not subject to interpretation, they are hard and fast. Often, when the ship is changing course it becomes tedious to maintain the DR plot. This is a given and known fact; however, the importance of keeping the plot up to date can't be stressed enough.

These rules specify when a DR position shall be plotted:

#	Rule
1.	A DR position shall be plotted each hour on the hour.
2.	A DR position shall be plotted at the time of every course change.
3.	A DR position shall be plotted at the time of every speed change.
4.	A DR position shall be plotted at the time of a fix or running fix.
5.	A DR position shall be plotted at the time of obtaining a single LOP.
6.	A new course line shall be plotted from each new fix or running fix.

Terms Associated with the DR Plot

Definition Table Use the following table to identify and learn the meanings of terms associated with DR:

Term	Definition
Heading	The ship's heading is always expressed in degrees measured clockwise from 000° through 360°. Commonly referred to as the ship's head, the heading can be referenced from true north, magnetic north, or compass. The ship's head is always changing due to the constant yawing motion caused by the effects of the sea and steering errors.
Course	The course is the direction on which the ship is to be steered. As an example, the helmsman is ordered to <u>come left steer new course 090° T</u> . The helmsman would respond by putting the rudder left and steadying the ship on new course 090°T.
Course Line	The course line is the graphical representation of the course that is being steered laid on to the chart. Looking back at our example, let's assume the original course was 094°T. The chart would have had a 094°T course line laid on it. When the helm was ordered to steer 090°T, a new course line of 090°T would be laid on the chart.
Speed	This is the ship's ordered speed. For example, let's assume that ordered speed is 12 knots. For purposes of DR, we assume that the ship will travel 12 nautical miles in 1 hour
DR Position	This position is determined by laying out the ship's course (course line) and speed on the chart. A DR position does not take into account any current that may speed or slow the ship.
Estimated Position	This is a best guess position using available information. In practical usage, it starts with the DR position and adds other data such as the estimated speed and set of the current.
Fix	This position is established at a specific time that is believed of high accuracy. With the recent addition of Global Positioning System (GPS) WRN-6 satellite fix data, it is now possible to obtain a highly accurate fix 24 hours a day.

Time, Speed, and Distance

Basics

Time, speed, and distance are related by the formula: distance = speed x time. Therefore, if any two of the three quantities are known, the third can be found. The units must be consistent. (The distance scales on nautical charts use nautical miles and yards, unless otherwise stated on the chart. A nautical mile is equal to 2,000 yards.) Thus, if speed is measured in knots and time in hours, the answer is in nautical miles. Similarly, if distance is measured in nautical miles and time in hours, the answer is in knots. If distance is measured in yards and time in minutes, the answer is in yards per minute.

Table 19 of *Bowditch* is a speed, time, and distance table that supplies one of the three values if the other two are known. It is intended primarily for use in finding the distance steamed in a given time at a known speed.

Solving the Time, Speed, and Distance Triangle

The following formulas may be used if the speed is measured in knots, the distance in nautical miles, and the time in hours and/or tenths of hours (0.1 hour = 6 minutes).

Distance = Speed x Time
Speed = Distance ÷ Time
Time = Distance ÷ Speed

<u>Example 1</u>. Your ship steams for a period of 4 l/2 hours and covers a distance of 54 nautical miles. What is your speed?

$$S = \frac{D}{T} \qquad S = \frac{54}{4.5} \qquad S = 12 \text{ knots}$$

In example 1, time was given in hours and tenths. When time is given or required in minutes, the same formulas, slightly changed, are still used.

Time, Speed, and Distance, Continued

$$Distance = \frac{Speed \times Time}{60} \text{ (minutes)}$$

$$Speed = \frac{Distance \times 60}{Speed}$$

<u>Example 2.</u> How many minutes (m) are required for a vessel to steam a distance of 7 nautical miles at a speed of 7.5 knots?

$$T(m) = \frac{D \times 60}{S} \qquad T(m) = \frac{7 \times 60}{7.5}$$

$$T(m) = \frac{420}{7.5} \qquad T = 56 \text{ minutes}$$

The following is an aid to help you remember these formulas.
Simply place the letters in a triangle, as shown in figure 8-1. For distance (D), place your finger over the D and you have S x T. For speed (S), cover the S and you have D ÷ T. For time (T), cover the T and you have
D ÷ S

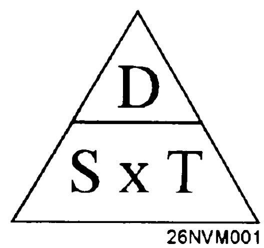


Figure 8-1. T, S, and D triangle.

3-Minute Rule

Another way of solving problems of distance, speed, and time is by using the 3-minute rule. The 3-minute rule will help solve mathematical computations without a nomogram or calculator. The rule states:

The distance traveled in yards over 3 minutes divided by 100 equals the speed in knots. To simplify, just drop two zeros from any distance traveled in yard in any 3 minute period.

<u>Example 1</u>: Ship travels 1,600 yd. in 3 min. 1,600/100 = 16 (Speed is 16 knots).

<u>Example 2</u>: Ship's speed is 16 kn for 3 min. 16 x 100 = 1,600 yd.

Using the Nautical Slide Rule

Procedure

To simplify speed, time, and distance solutions, most Quartermasters use a circular slide rule (fig. 8-2), commonly known as a nautical slide rule. When you enter two known variables on the appropriate scales, the third value can be found.

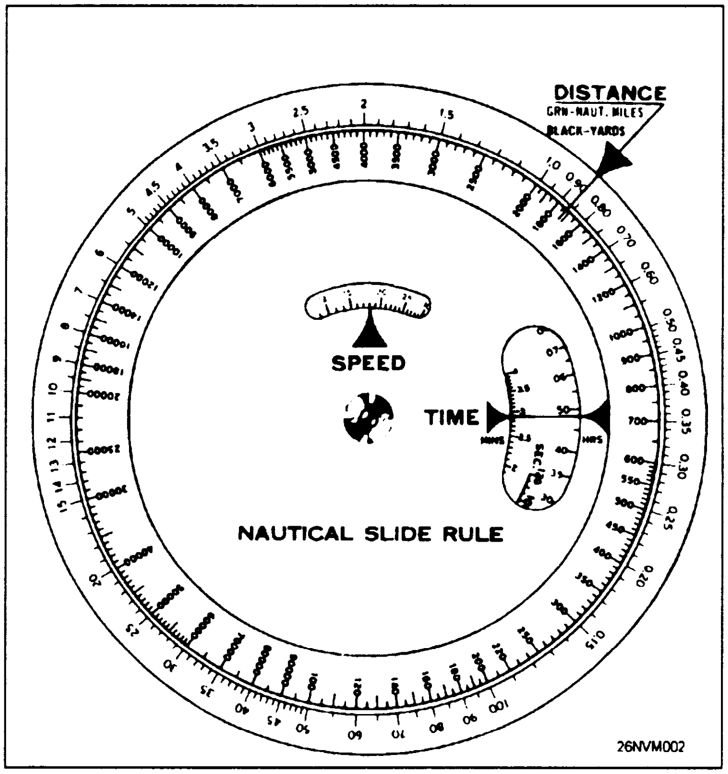


Figure 8-2. Nautical slide rule.

Caution

Do NOT rely solely on the nautical slide rule to calculate time, speed, and distance problems. A problem will surely arise when the slide rule is not available. Additionally, you cannot use a nautical slide rule when taking advancement examinations.

Practice Time, Speed, and Distance Problems

1. Using the formula for solving time, speed, and distance problems, solve each of the following:

	TIME	SPEED	DISTANCE
a.	______	14 kt	146 nmi
b.	12 min	______	.6 nmi
c.	73.5 hr	16 kt	______
d.	76 hr	______	874 nmi
e.	9h.r	8 kt	______
f.	______	15 kt	1485 nmi
g.	______	18 kt	918 nmi
h.	11 hr	______	132 nmi

2. The 3-minute rule simply states that distance traveled in yards in____minutes divided by____ equals____ .

3. Using the 3-minute rule, solve each of the following, rounding to the nearest tenth where required.

	TIME	SPEED	DISTANCE
a.	3 min	______	750 yd
b.	6 min	______	1420 yd
c.	3 min	______	765 yd
d.	6 min	______	1140 yd
e.	3 min	______	414 yd
f.	3 min	______	840 yd

Measuring the Ship's Speed

Methods

Speed can be determined directly using special instruments or indirectly by means of distance and time.

The first method of measuring a ship's speed and distance involves the use of instruments that directly measure a ship's motion through the water. Such instruments are called logs. The three types of modern logs in common use today are: the pitot-static log, the impeller log, and the electromagnetic log. Figure 8-3 is an example of a speed log indicator. Each of these logs requires the use of a device called a rodmeter, which is basically a blade or rod that is projected through the bottom of the hull. The rodmeter contains the sensing devices that determine speed. You must be careful not to lower the rodmeter in shallow water as it may strike the bottom.

Another way of determining speed and distance is indirectly using engine or shaft revolutions. This data can be derived, or verified, by running the ship over a measured mile. To do this, you run the measured mile at given engine rpm's, and note the time it takes you to travel the mile. Then using the speed, time, and distance formulas previously given, you determine the speed for that rpm. A table, graph, or both are then prepared that relate rpm to ship's speed.

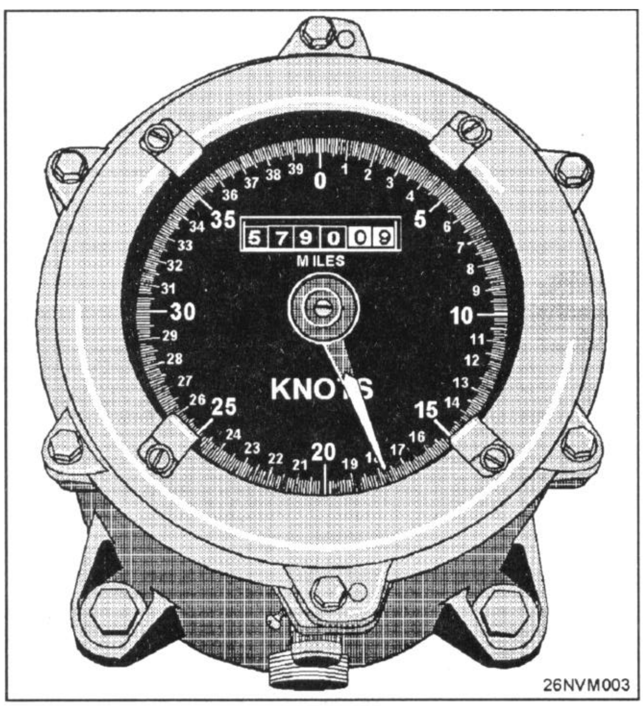


Figure 8-3. Speed log indicator.

Example of a DR Plot

Example

Figure 8-4 represents a sample DR plot. At 0900 your ship departs point A en route to point B on course 090°T, speed 12 knots. In this particular example, DRs are laid out every hour; you expect to arrive at point B at 1300.

At 1200, you obtain a fix which places your ship 180°T, 5 miles from your 1200 DR position (point X). If you were to maintain your original course of 090°T, you will miss your destination; therefore, a correction is necessary.

Since time was required to record and evaluate your fix and to decide a new course and speed to reach your destination (point B), the change cannot occur at the 1200 fix. Instead, you must DR ahead some point in time. In this case, the navigator plots a 1210 DR position based on the old, and still maintained, course and speed. From here the navigator calculates the new course of 050° T, speed 15 knots. It is important to remember that the course line will continue in the direction and speed originally ordered during the time spent obtaining and plotting the fix and while deciding a new course and speed.

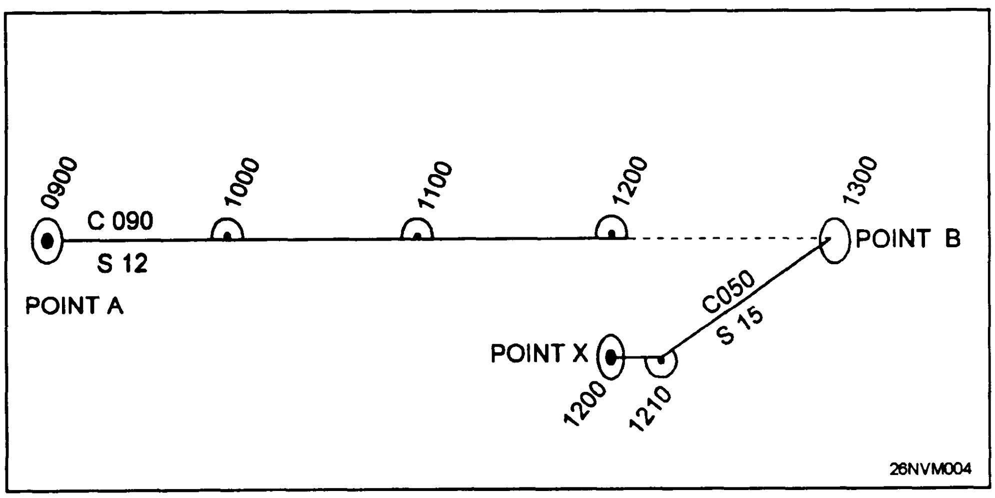
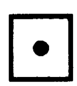


Figure 8-4. Example DR plot.

Labeling the DR Plot

Symbols

The symbol for a DR position is a small semicircle around a small dot on a straight segment of a course line (fig. 8-5); it will be more or less than a semicircle when plotted at a change in direction. The letters DR are not used. Time, to the nearest minute, stated in the 24-hour system as a 4-digit number is written nearby. All symbols for labeling positions are also shown.

SYMBOL	DESCRIPTIVE LABEL	MEANING
	FIX	AN ACCURATE POSITION DETERMINED WITHOUT REFERENCE TO ANY PREVIOUS POSITION. ESTABLISHED BY VISUAL OR CELESTIAL OBSERVATIONS.
	FIX	A RELATIVELY ACCURATE POSITION, DETERMINED BY ELECTRONIC MEANS. THIS SYMBOL IS ALSO USED FOR A FIX WHEN SIMULTANEOUSLY FIXING BY TWO MEANS, e.g., VISUAL AND RADAR; SOMETIMES USED FOR RADIO/NAVIGATION FIXES, WITHOUT REFERENCE TO ANY FORMER POSITION.
	DR	DEAD RECKON POSITION. ADVANCED FROM A PREVIOUS KNOWN POSITION OR FIX. COURSE AND SPEED ARE RECKONED WITHOUT ALLOWANCE FOR WIND OR CURRENT.
	EP	ESTIMATED POSITION. IS THE MOST PROBABLE POSITION OF A VESSEL, DETERMINED FROM DATA OF QUESTIONABLE ACCURACY, SUCH AS APPLYING ESTIMATED CURRENT AND WIND CORRECTIONS TO A DR POSITION.

26NVM005

Figure 8-5. Symbols used for labeling positions along a course line.

Answers:

1. a. 10.4 hrs, b. 3 k, c. 1176 nmi, d. 11.5 k, e. 72 nmi, f. 99 hrs, g. 51 hrs, h. 12 k.

2. 3/100/speed in knots

3. a. 7.5 k, b. 7.1 k, c. 7.7 k, d. 5.7 k, e. 4.1 k, f. 8.4 k

Plan of Intended Movement (PIM)

Basics

Prior to any ship getting under way, a PIM must be formed. Normally, the senior Quartermaster and the navigator will discuss the best possible routes for the ship to follow. Messages are then sent to group commanders and the ship gets under way. As the QMOW, you will be tasked with tracking the ship's progress.

Tracking is directly related to time, speed, and distance calculation. Figure 8-6 represents a ships track with PIM times and dates annotated. As a rule, PIM is laid out for every 4 hours GMT. When referring to the ship's position in relation to PIM, you should express any values as time ahead or behind PIM. Let's look at an example.

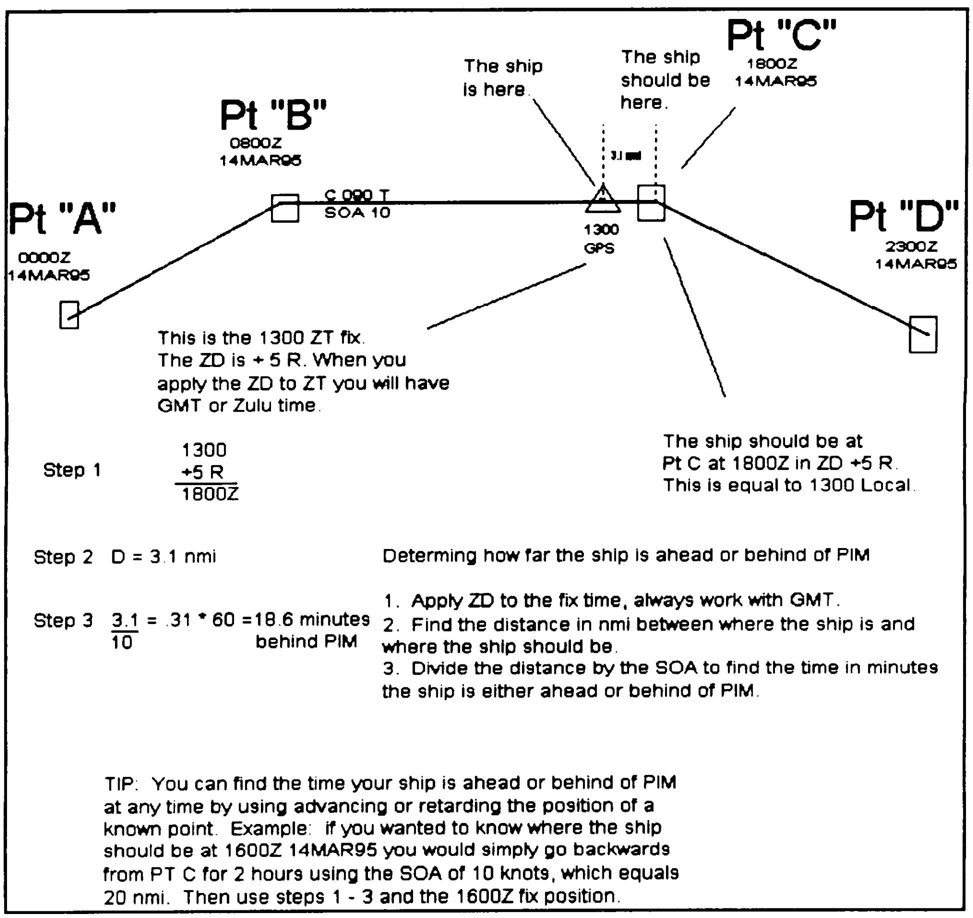


Figure 8-6. Example PIM calculation.

Basics

Let's put together what we've learned about the DR plot, the tools of the trade, and the techniques the Quartermaster uses.

Tools used to project lines, scribe arcs, measure angles and distances, and do a host of other jobs are just some of the hand tools you will use as a Quartermaster. Items such as pencils, parallel rulers, compasses, and dividers are a MUST on any bridge or in any chart room.

Tools of the Trade

Pencils: Primary among these tools is the pencil you use. There are several grades or hardness of lead. The softer grades, such as the No. 2, are ideal for plotting positions on the chart and for other general uses around the bridge. No. 3 pencils are considerably harder, will hold a point longer, and will usually sharpen better for use in drawing fine lines as will be required when the QM wants to plot stars, draw course lines, or do other chart work that requires the use of better than average lines to show the condition to be depicted. Under most conditions, only the Nos. 2 and 3 grade pencils will be necessary.

Parallel Rulers: Parallel rulers are instruments used for moving lines parallel to themselves, determining direction from the compass rose, and laying out course lines. These are, of course, only a few of the uses of parallel rulers. Some of the other uses include drawing straight lines, advancing lines of position, checking ranges, plotting fixes, and measuring direction from one given point to another. There are other devices available which are easier to use and will do the same job as parallel rulers. The Weems parallel plotter (fig. 8-7) is the most widely used variation of the parallel ruler.

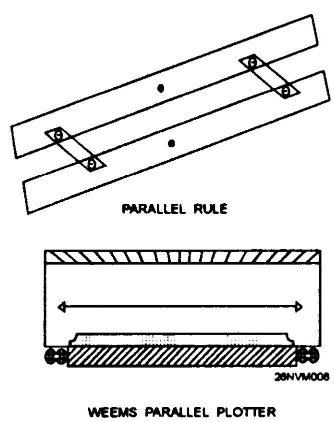


Figure 8-7. A parallel rule (top) and a Weems parallel plotter.

Tools of the Trade, continued

Compasses: Compasses are not to be confused with the direction finding compass such as the magnetic or gyrocompass. The compasses referred to here are tools that are very similar in appearance to the divider. The distinction between dividers and compasses is that while both divider legs are fitted with needles, the compass legs are fitted with a needle on one leg and a marking lead or pencil on the other.

Compasses are useful for scribing circles and arcs such as radar ranges or perhaps showing the limits of a light's visibility. Dividers and compasses (fig. 8-8) will give best results when the adjustment screw at the hinged end is kept tight enough to permit ready use but prevent slippage. The needle points should be sharp, extended to the same length, and locked securely using the locking screw provided.

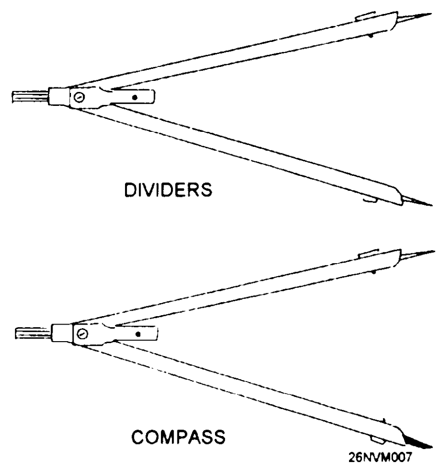


Figure 8-8. Compass and dividers.

A variation of the compass, called a beam compass, is used when a greater spread is required than an ordinary compass can accommodate. The beam compass is simply a long bar with a needle point at one end and a marking lead or pencil at the other end; both are adjustable. This compass is very useful when using large-scale charts such as harbor charts.

Dividers: A pair of dividers is an instrument or tool used to measure the difference between two given points. It consists of two small pieces of metal, plastic, or wood, hinged at one end, allowing the opposite ends to be separated. There are needles or points placed in the ends of both legs which enable the user to obtain a more accurate measurement and allow the tool to be swung from one length to another without slipping. There are many sizes of dividers, but the 5- and 6-inch sizes have been found to be the most popular and useful. Larger dividers are handy at times, but can be clumsy to use.

Plotting Techniques

General Procedure

To travel accurately and safely from point to point on Earth's surface, charts have been constructed to show the locations of most all prominent places. Using these charts, a navigator can plan the voyages. By drawing a line on the chart from one place to another, a navigator establishes a line known as a course line, the purpose of which is simply to provide a graphic representation of a vessel's course. Careful attention must be paid to ensure that there are no dangers to navigation, such as rocks, reefs, islands, and so forth, along the route of intended travel. From this line, the navigator determines the direction in which the ship must sail to arrive at the desired location. By measuring the distance between the two places and knowing the speed of the ship, the navigator computes how long the voyage will take.

As defined in the terms table, course (C) is horizontal direction of travel, expressed as angular distance from a reference direction, usually from 000° clockwise through 360°. For marine navigation, the term course applies to the direction to be steered, which sometimes differs from the direction you intend to make good over the ground. Course is most often designated as true, but may also be designated as magnetic, compass, or gyro.

Often while the ship is following the intended track, it will be necessary to change course to avoid other ships or make adjustments for current that sets the ship off the intended track.

Maintaining the DR plot is a matter of closely following the six rules of DR. Let's look at an example of what is required to maintain a sample plot. The example shown in figure 8-9 illustrates a typical DR plot. At 0900 your ship departs point A en route to point B on course 065°T, speed 10 knots. In this particular example, DRs are laid out every 30 minutes; you expect to arrive at point B at 1200. At 0941 you change course to avoid shipping traffic. At 1000 you obtain a fix which places your ship right of your track line. Based on the 1000 fix, you recommend course 075°T to arrive at point B on time.

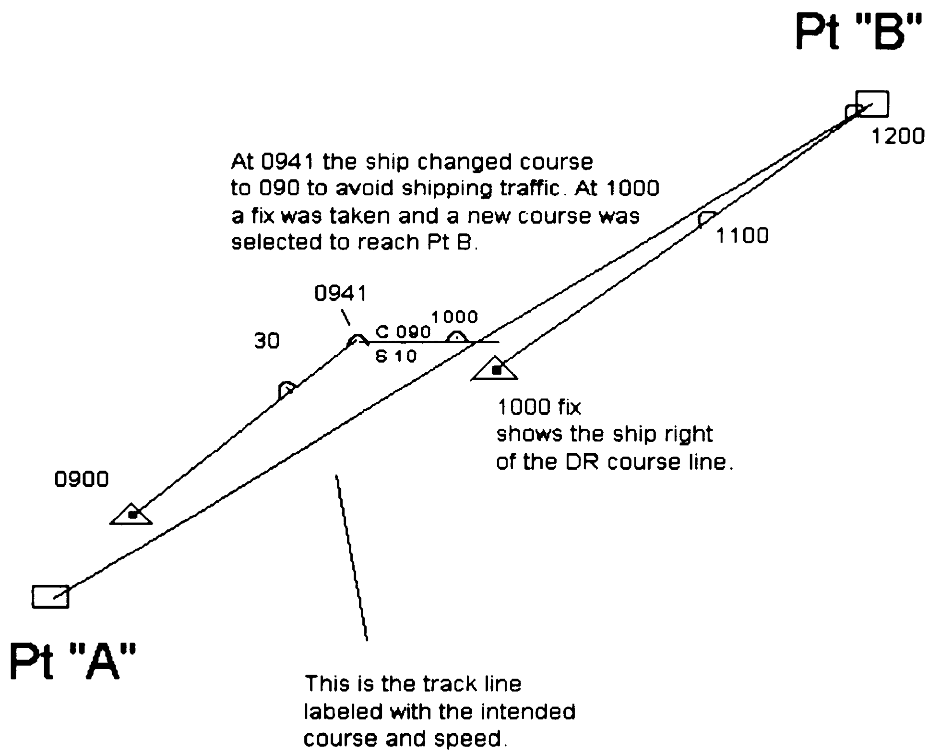


Figure 8-9. Sample plot.

This example is for illustration purposes only. In actual practice, the QMOW will normally obtain and plot a fix every hour while on the open ocean. The frequency of fixes is determined by the navigator. It is not unusual while in coastal waters for the QMOW to obtain and plot fixes each l/2 hour or even every 15 minutes.

Labeling the Course Line

Procedure

Figure 8-10 shows a typical layout and labeling of course lines. The label for direction is the letter *C* followed by three digits indicating true course in degrees; this is placed above the course line. If course lines are based on magnetic headings, the letter *M* is added following the digits.

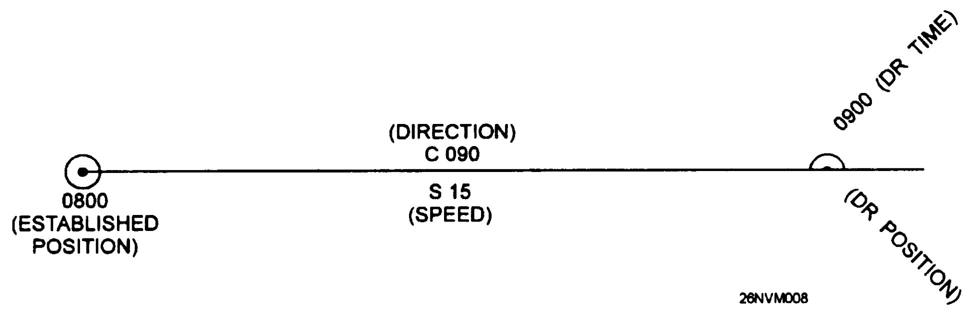


Figure 8-10. Labeled course line.

The intended speed, or the speed you wish to make good with respect to Earth, is known as speed of advance, or simply SOA. SOA is also used to designate the average speed that must be made good to arrive at a destination at a specified time. The letter S followed by numbers shows the intended speed. This is placed below the course line, usually directly beneath the direction label.

Emergency Plotting

There are times when you will be required to plot positions in emergency situations. The most common of these is during man overboard events. Your reaction time is critical. The preferred method is to use the WRN-6 to enter a waypoint and then drive the ship back to that point. You may also use this method using commercial Loran C receivers. You must consult the WRN-6 or Loran C operators manuals for step by step instructions.

<u>Leading Petty Officers</u>: Post detailed man overboard procedures at the chart table on the bridge. Hold training frequently on procedures, strive to obtain fix data within 3 seconds from sounding man overboard alarm.

Piloting

Introduction

Navigation becomes more demanding when your ship is near land or in restricted waters where there is an immediate danger of possible grounding. Piloting is the process of safely directing the movement of a vessel from one point to another involving frequent or continuous determination of a ship's position relative to geographical points, to a high order of accuracy.

Section Objectives

- List the three types of navigational observances used to determine a ship's position in piloting.
- Match the following navigation terms with their meanings:

a. true bearings	i. estimated position
b. relative bearing	f. piloting
c. fix	g. set & drift
d. speed of advance	h. line of position
e. course over ground	j. running fix

- List the procedures for obtaining visual bearings and radar ranges.
- State the best objects and proper order to obtain visual bearings and radar ranges.
- Convert relative bearings to true bearings.
- List the procedures for plotting a visual fix and a radar fix.
- List the procedures to set up and plot visual bearings with a PMP.
- List the methods used to compensate for gyro error on a PMP.
- State how to obtain a bearing and range from radar.
- Make proper entries in the Standard Navy Bearing Book.
- State the OPNAV instruction that regulates how to maintain a navigation plot.
- Identify the general requirements for LOPs when maintaining a navigation plot.

The Navigation Team

Piloting must be done on a chart. You must construct a plot based upon accurate navigational observations of charted features. These observations of charted features include:

- bearings to visible objects
- distances to objects
- depth sounding

To effectively navigate in confined waters, a team of personnel must assist the navigator. The navigation team composition is as follows:

Position	Responsibilities
Navigator	All navigation functions.
Assistant navigator	Supervises navigation team, assists the navigator.
Plotter	Plots bearing on the chart, DRs, calculates set and drift.
Bearing takers	Takes bearings on objects as directed by the bearing recorder.
Bearing recorder	Relays bearing to the plotter, records bearings, provides all stations with marks.
Fathometer operator	Reports depth of the water on each mark.
CIC phone talker	Provides the bridge with navigation data from CIC as requested.

The Navigation Brief

In all cases, a ship needs a plan of action prior to getting under way or entering port. This plan, called the Navigation Brief, is a detailed description of all aspects of the ship’s actions while in piloting waters. Information concerning the ship’s track, navigation aids to be used, tide and current data, emergency anchorages, and other data are all contained in the Navigation Brief.

The actual construction of the Navigation Brief will be covered in detail in chapter 12.

Lines of Position and Fixes

Defined

A line of position (LOP) is a line established by observations or measurement on which a vessel can be expected to be located. The concept of a LOP is extremely important in piloting. From a single LOP, one can safely assume that the ship is located somewhere along that line.

A LOP may be straight (for bearings) or curved (for ranges). To obtain a high degree of accuracy when fixing the ship's position, you must use three or more LOPs.

<u>Accuracy:</u> Factors such as chart errors, human limitations, and equipment errors may affect the accuracy of a LOP. The accuracy of any single LOP can be checked by comparison with two or more LOPS that are taken simultaneously. A bearing will be suspect if it plots away from two other LOPs.

Fixes

A fix is the point of intersection of two or more simultaneously obtained LOPS indicating your ship's exact position on the chart. The accuracy of a fix obtained from two LOPS is almost always questionable. Since we have already stated that accuracy is of the utmost importance in piloting, you must always strive to obtain *three* or *more* lines of position for an accurate fix.

Labeling LOPs

Any single LOP that is obtained must be labeled with the time that it was obtained. This is necessary if it is to be in a running fix. An unlabeled LOP can mistakenly be used and become a source of error.

In the practice of piloting, single LOPS are not common because bearings on objects are taken at the same time by the bearing takers. The fix resulting from these bearings is labeled with the time the bearings were taken.

Selecting Landmarks for LOPS

The angle between selected objects is the most important factor to consider when selecting objects to fix the ship's position from. For three simultaneous LOPS to provide the best fix, they should be located 120° apart. This is often impossible in practical application. Normally, the assistant navigator or plotter will select possible objects to obtain bearing and the resulting fixes from. Use of conspicuous landmarks is always desirable. Lighted towers, water tanks, and buildings are some possibilities.

Determining the Ship's Position Using True Bearings

Procedure

The following table identifies the process of determining the ship's position by true bearings.

Step	Action
1.	The assistant navigator or plotter selects objects to shoot bearing on.
2.	The bearing recorder informs the bearing takers of the objects they are to shoot.
3.	At the appropriate time, the bearing recorder gives a lo-second standby and on the minute gives the order "MARK" to the bearing takers.
4.	At the exact moment, the bearing takers shoot and relay the values of the bearings to the bearing recorder. **Rule:** It is common for both bearing takers to be required to shoot bearings on more than one object. Bearing takers MUST shoot objects closest to the beam of the ship first, then shoot objects closest to the bow, and finally objects closest to the stern. **Memory Aid: BEAM, BOW, STERN**
5.	The bearing recorder relays the bearings to the plotter.
6.	The plotter plots all bearings, labels the resulting fix, determines set and drift, and DRs out on the track.
7.	The navigator analyzes the fix data and makes reports and recommendations on actions to be taken to the officer of the deck.

Skills

The table explained only the process that is generally followed to fix the ship's position using true bearings. Learning the actual skills required to function as a member of the piloting team requires many hours of OJT and meeting requirements for PQS. Inexperienced QMs normally begin training on the piloting team as bearing takers and move to stations requiring more responsibilities as their individual skills progress.

Determining the Ship's Position Using Relative Bearings

Relative Bearings

A relative bearing refers to a bearing taken on an object relative to the ship's heading. They are measured from 000° through 360°.

<u>Example:</u> If a ship is on course 090° T and a bearing taker shoots light "A", 020° relative, this means that light "A" is 20° to the right of the ship's head. To convert relative bearings to true bearings, apply the formula SH + RB = (subtract 360 from T if over 360°). SH is ship's head, RB is relative bearing, and T is the true bearing.

When to Use Relative Bearings

In almost all cases, relative bearing navigation will be used when a casualty occurs to the gyrocompass. There are several methods available for use to find the ship's position using relative bearings. In this text, we will cover only the preferred method. Complete information on using relative bearings can be found in *Dutton's.*

Procedure

Use the following table to use relative bearings to fix the ship's position.

<u>Rule:</u> The helmsman must mark the ship's head each time a round of bearings are taken; the bearing recorder must start a new column to record ship's head data.

Step	Action
1.	Direct bearing takers to shift to relative bearings using the outer ring of the pelorus; shoot a round of bearings.
2.	Align the PMP ruler to the ships head. **<u>Example:</u>** Cse 200° T
3.	With a sharp white grease pencil, mark compass deviation from the deviation tables onto the PMP scale. Remember + W - E. **<u>Example:</u>** For 5° W deviation, mark 205° on PMP scale. 205° is the Compass Cse the helmsman must steer. When you recommend new courses, use magnetic courses indicated by the grease pencil mark.
4.	Now mark the 180° and 0° on the PMP scale with the grease pencil. Use these marks to align the relative bearings.
5.	Plot the round of bearings using the 180° and 0° grease pencil marks.

Figure 8-11 on the following page shows a PMP that is set up for relative bearing navigation.

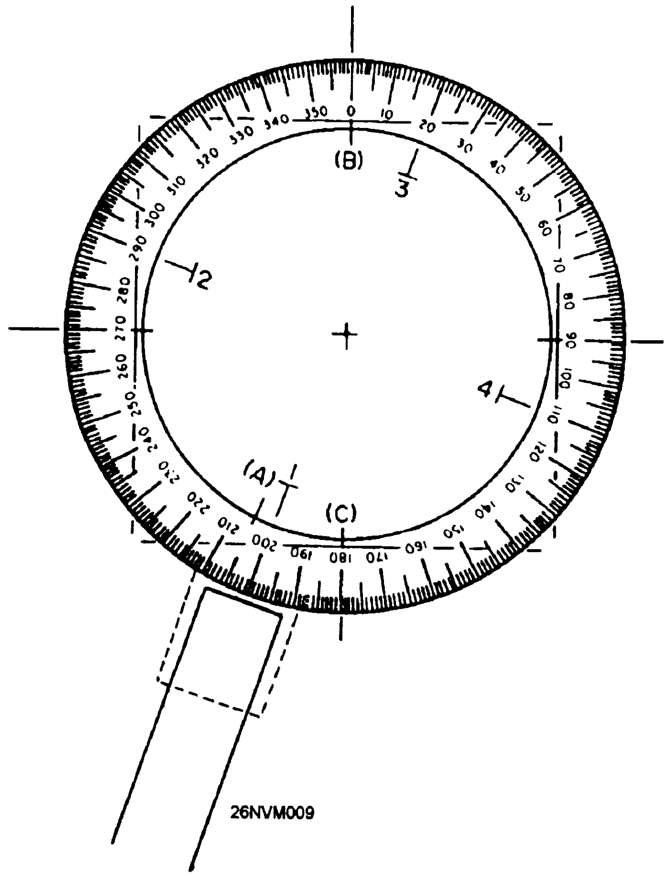


Figure 8-11. PMP set up for relative bearing navigation.

Accuracy

The results of a relative bearing fix are directly related to the accuracy of the deviation table. If the compass deviation listed is in error by 2°, then all bearings may be off by 2°. There is a way to check the accuracy of the deviation tables for any area in which the ship is operating. Comparing the deviation table to the entries in the Magnetic Compass Record Book may at times give an indication to the accuracy of the deviation tables. Often, interpolation is required. Any decision to deviate from values given in the deviation tables must be made by the navigator and recorded in the Standard Bearing Book.

The Marine Sextant

The Marine Sextant

The marine sextant's only function is to measure angles, either horizontally or vertically. The most common use of the sextant is for celestial observations using vertical angles between celestial objects and the horizon. It is also used for fixing your position using horizontal angles between three charted objects. In this chapter, we will concern ourselves with the latter method. Before we can learn how to fix the ships position using the marine sextant, we need to learn how to operate the marine sextant. Figure 8-12 shows the parts of a marine sextant.

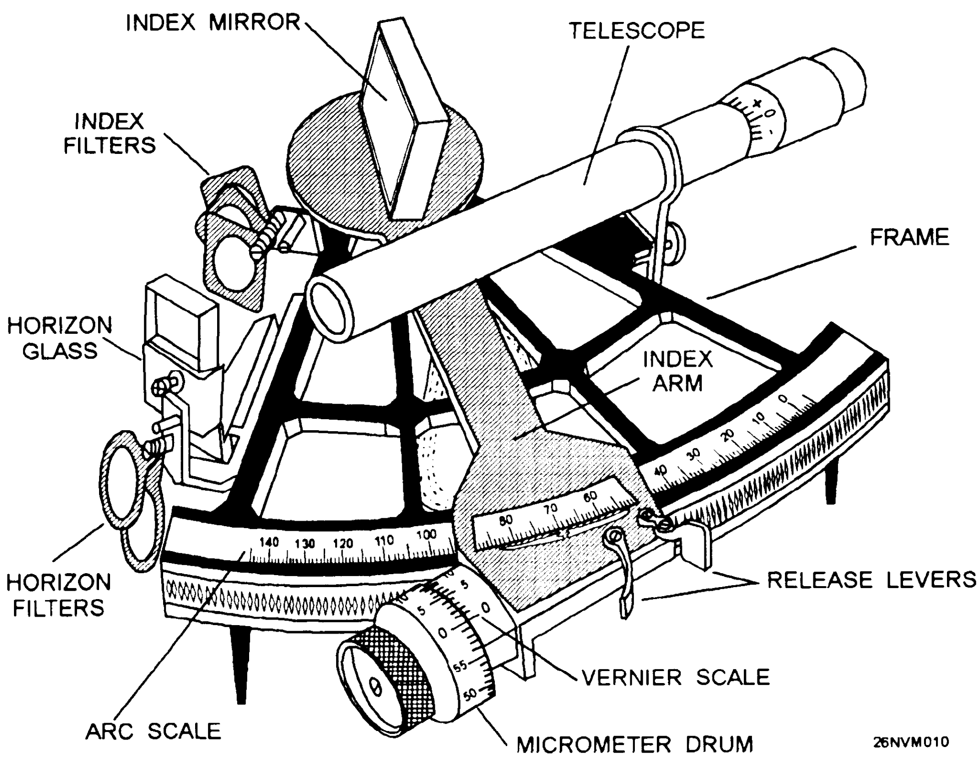


Figure 8-12. The marine sextant.

Parts and Functions

These are the parts and functions of the marine sextant:

Part	Description of Function
Arc scale	Indicates the number of degrees of an angle.
Index arm	Pivots at one end to allow the attached index mirror to reflect an object onto the horizon glass and swings along the arc scale on the other end to indicate what the angle measures.
Micrometer drum	Rotates to make fine adjustments when measuring angles and indicates minutes of a degree of angle. It is attached to the lower end of the index arm. One complete rotation moves the index arm 1° along the arc scale. The drum has 60 graduations, each representing 1' of arc.
Vernier scale	Indicates tenths of a degree of angle. It is attached on the index arm adjacent to the micrometer drum and has 10 graduations, each representing 0.1' of arc.
Index mirror	Reflects objects onto the horizon glass.
Horizon glass	Allows the observer to view one object directly on one side while observing a second object reflected next to it. The half of the horizon glass next to the frame is silvered to make that portion of the glass a mirror; the other half is clear glass.
Telescope	Directs the line of sight of the observer to the horizon glass and magnifies the objects observed.
Filters	Protects the observer’s eyes when viewing the Sun.
Release levers	Disengages the index arm from the arc scale to allow the index arm to move freely.

How a Sextant Works

A reflected object from the index mirror can be brought into line with an object viewed directly by moving the index arm along the arc scale until the reflected object can be seen in the horizon glass. The angle measurement is read off the arc scale, micrometer drum, and vernier scale. Figure 8-13 shows how a sextant works.

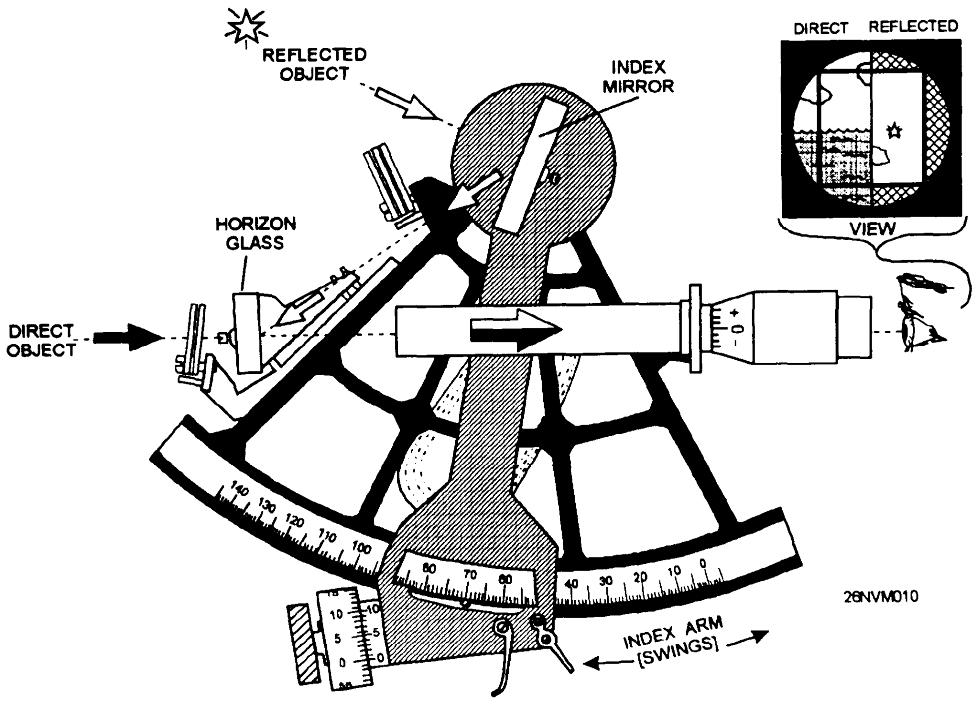


Figure 8-13. How a sextant works.

How to Read the Sextant

Reading a sextant angle involves properly understanding and interpreting the markings on the arc scale, micrometer drum, and vernier scale.

Follow these steps to properly read a sextant angle:

Step	Action
1.	Locate the position of the index arm mark on the arc scale.
2.	Determine which degrees the mark is between. The lower reading is the amount of whole degrees.
3.	Locate the position of the zero mark on the vernier scale.
4.	Determine which minutes the zero mark is between on the micrometer drum. The lower mark is the amount of whole minutes.
5.	On the vernier scale, determine which graduation mark is most nearly in line with one of the graduation marks on the micrometer drum. This mark indicates the amount of tenths of a minute. **Note:** To make sure you select the correct mark, look at the vernier marks on each side of the one that appears to be in line with a drum mark. Both vernier marks will be on the inside of the closest drum marks.

Figure 8-14 is an example of a sextant angle of 67° 40.6'.

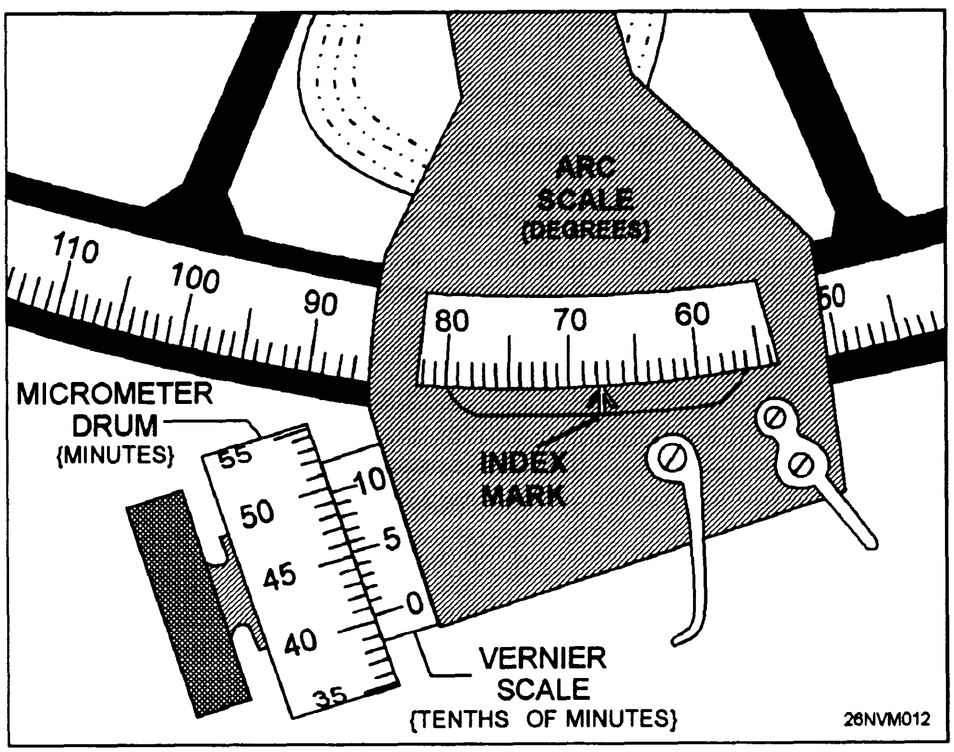


Figure 8-14. Reading a sextant angle.

Finding the Index Error

The marine sextant will measure angles accurately if it is properly adjusted and used correctly. The senior Quartermaster is responsible for making sure that any *adjustable* errors are properly corrected before the sextant is used. However, practically every sextant has a small error called *index error* (IC), which cannot be adjusted.

Use these procedures to determine index error *every time* you use a sextant to measure angles. An *index error correction* must then be applied (added or subtracted) to every angle that is taken.

Follow these steps to determine index error:

<table>
<tr><th>Step</th><th>Action</th></tr>
<tr><td>1.</td><td>Hold the sextant in a vertical position with your right hand on the handle.</td></tr>
<tr><td>2.</td><td>Move the index arm to approximately zero on the arc scale with your left hand using the release levers.</td></tr>
<tr><td>3.</td><td>View the horizon through the telescope.</td></tr>
<tr><td>4.</td><td>Rotate the micrometer drum to align the reflected image of the horizon with the direct image.</td></tr>
<tr><td>5.</td><td>Take a reading.</td></tr>
<tr><td>6.</td><td>Repeat steps 3 through 5 at least two more times.</td></tr>
<tr><td>7.</td><td>Average the three readings to determine index error.</td></tr>
<tr><td>8.</td><td>Apply the index error correction to your angle.
<table>
<tr><th>IF index error is...</th><th>THEN...</th></tr>
<tr><td>zero</td><td>no correction is needed.</td></tr>
<tr><td>positive</td><td>subtract the amount of index error.</td></tr>
<tr><td>negative</td><td>add the index error.</td></tr>
</table></td></tr>
</table>

View of the Horizon

Figure 8-15 is an illustration of what you should see when trying to determine index error.

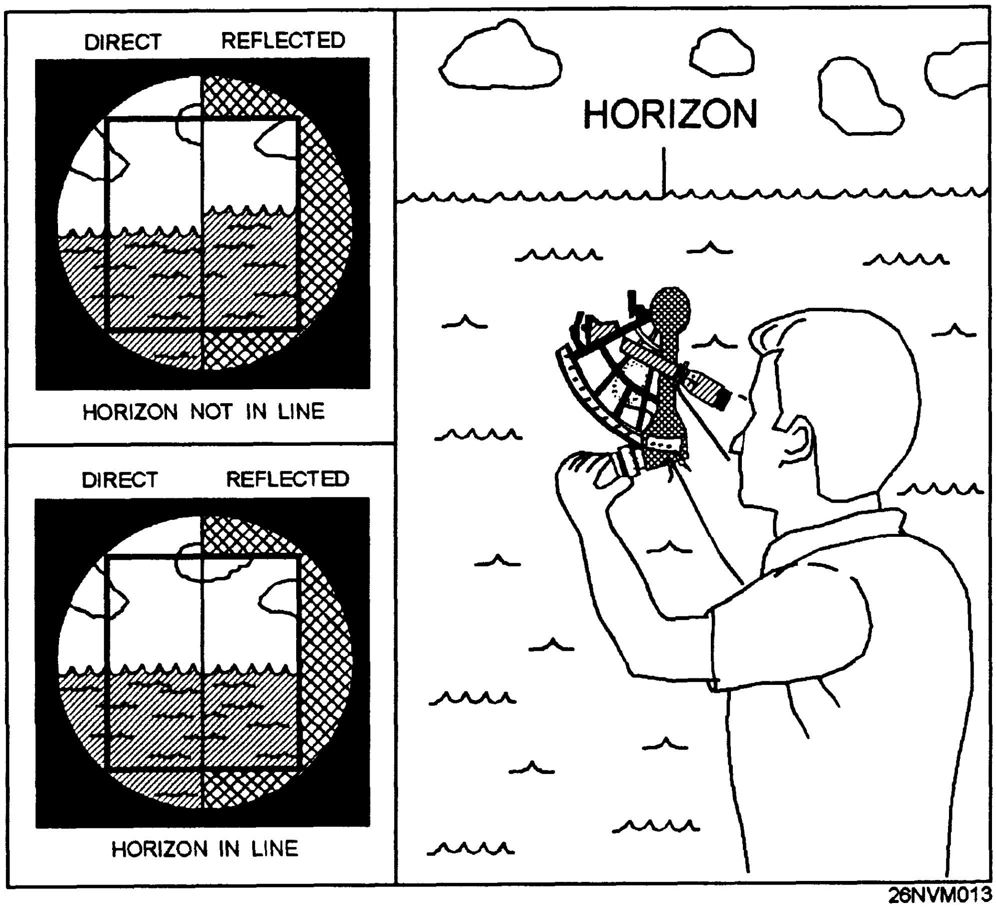


Figure 8-15. Direct and reflected views of the horizon.

How a Reading of 0.0 Index Error Looks

An example of what the scales would look like if there were *no index error* is shown in figure 8-16. Notice that the index mark is directly under the 0 on the arc scale and the 0 mark on the vernier scale lines up directly with the 0 mark on the micrometer drum.

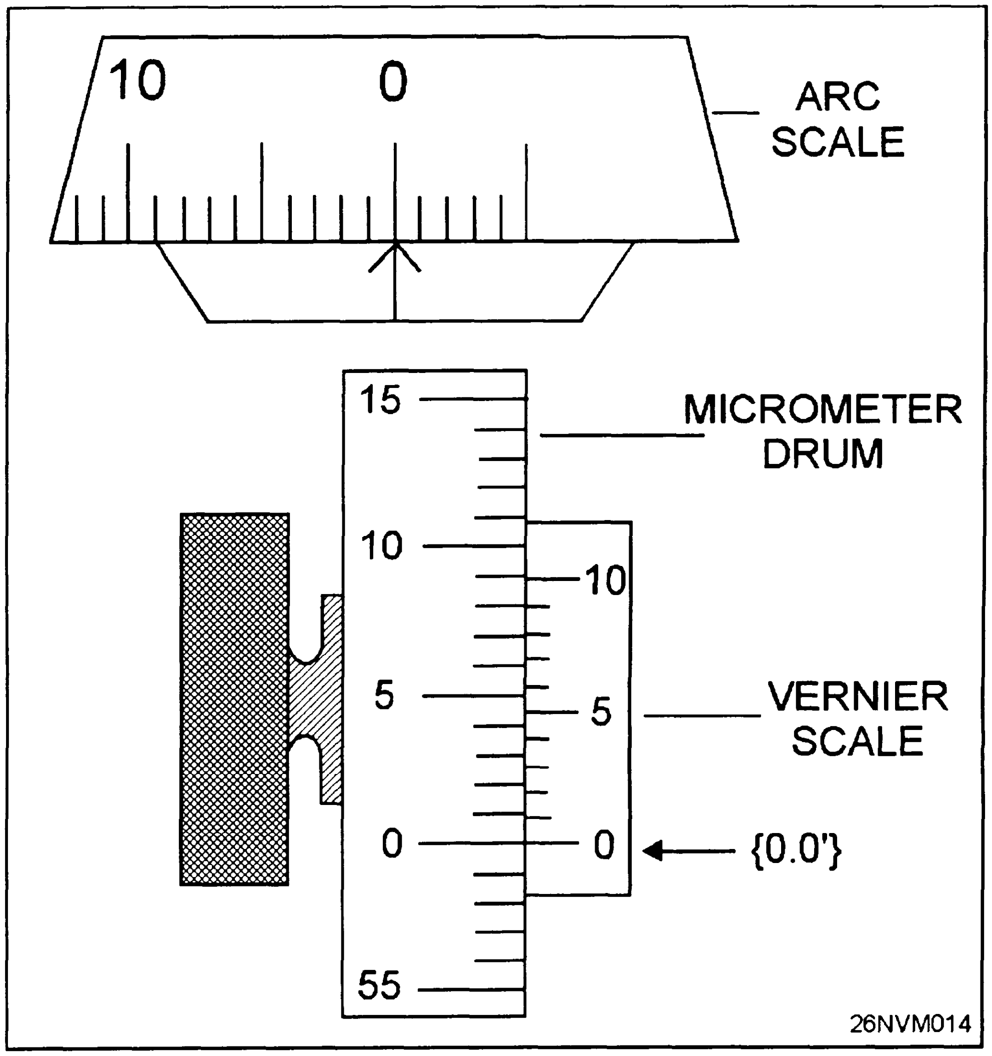


Figure 8-16. A reading of 0.0 index error.

Reading Positive Index Error

An example of what the scales would look like if you had a *positive index error* is shown in figure 8-17. Notice that the index mark is to the left of the 0 on the arc scale and that the 0 on the vernier scale is above the 0 on the micrometer drum, indicating a positive error. The micrometer and vernier scale lineup directly at the 0.4' line on the vernier scale, indicating an index error of +0.4'. This would be *subtracted* from any angles taken with this sextant to obtain an accurate angle.

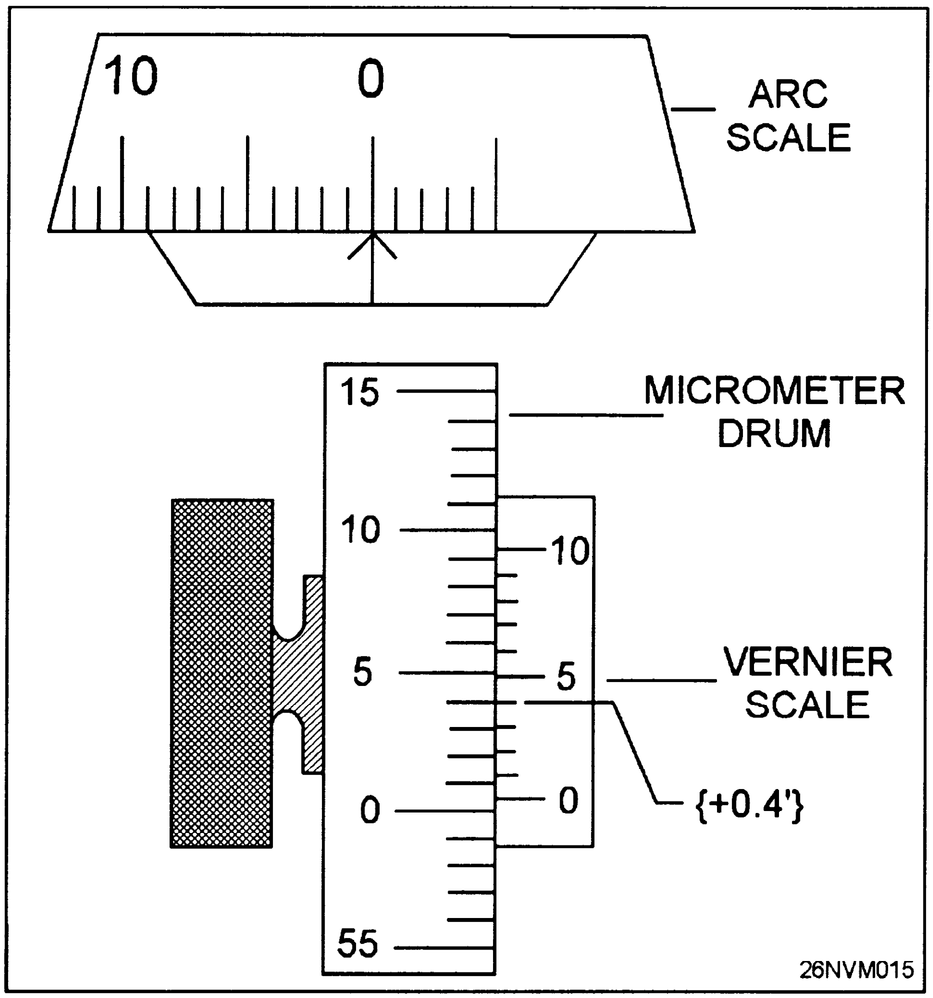


Figure 8-17. Positive index error.

Reading Negative Index Error

An example of a reading of negative index error is shown in figure 8-18. Notice that the index mark is to the right of the 0 on the arc scale and the 0 on the vernier scale is below the 0 on the micrometer drum. The micrometer scale and vernier scale line up directly on the 0.7' mark of the vernier scale, indicating a -0.7' index error. The correction would be added to any angles shot with the sextant.

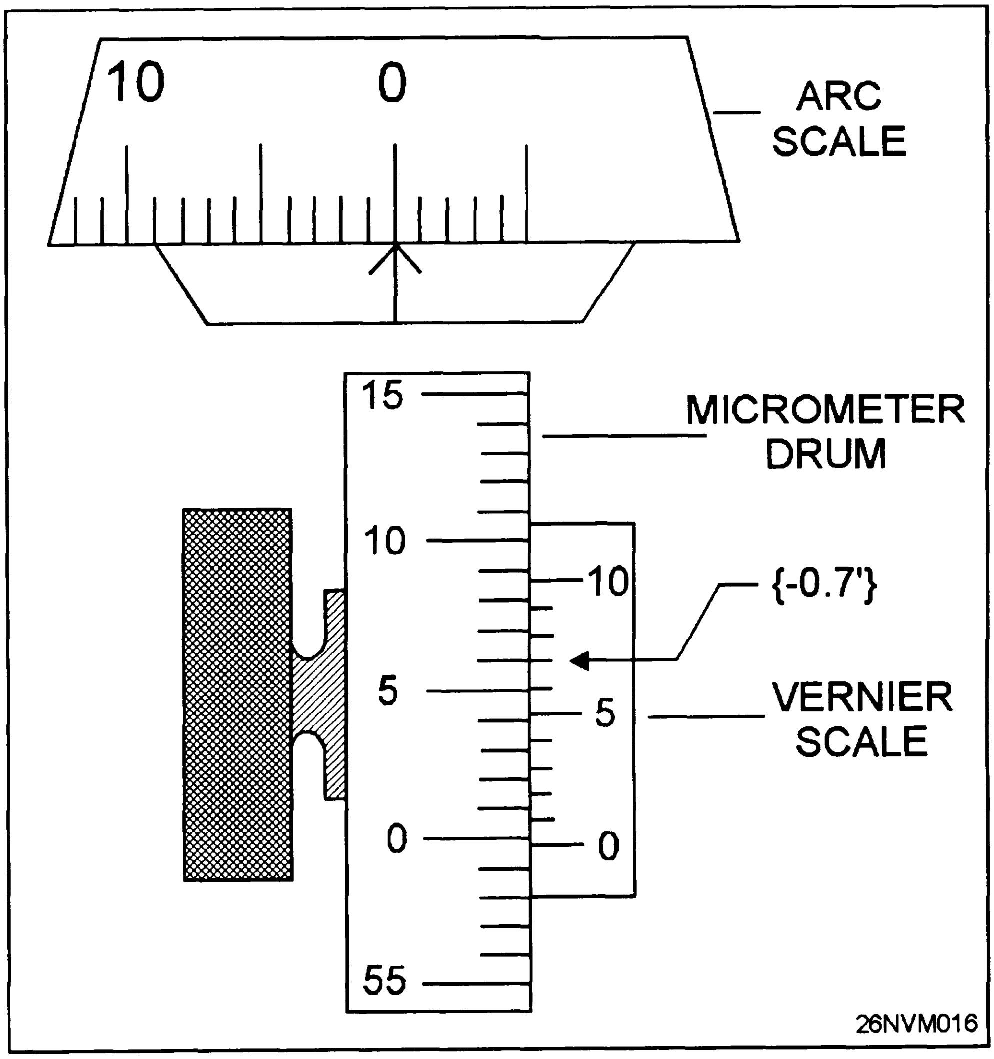


Figure 8-18. Negative index error.

Determining the Ship's Position Using Sextant Angles

Accuracy and Usage

Horizontal sextant angles give fixes of great accuracy that are not affected by any error of the compass. A fix by horizontal sextant angles is labeled the same as a visual fix with a small circle around the position and the time of the fix close to the fix symbol.

Horizontal sextant angles used in conjunction with a computer-assisted positioning program are the most common method used by the Coast Guard to position aids to navigation.

Horizontal sextant angles should be taken as nearly simultaneously as possible, preferably by two people on a predetermined signal. However, one person can obtain both angles if the ship is not moving quickly.

Procedure

Rule: To obtain a fix using sextant angles, you must have *three fixed visual objects,* and those objects must be identifiable on the chart.

Follow these steps to obtain horizontal sextant angles:

Step	Action
1.	Hold the sextant horizontally with your right hand.
2.	View the left object directly through the telescope.
3.	Release the index arm with your left hand on the release levers and swing the arm so that the index mirror reflects the center object in the horizon glass below the left object.
4.	Rotate the micrometer drum to fine adjust the reflected object in line with the object viewed directly.
5.	Take a reading of the angle.
6.	Do you have two people taking angles? If yes, both angles are ready to be plotted. If no, repeat steps 1 through 5 using the center object viewed directly and the right object viewed reflected.

Select Three Objects

Figure 8-19 illustrates how three objects are needed to obtain two angles.

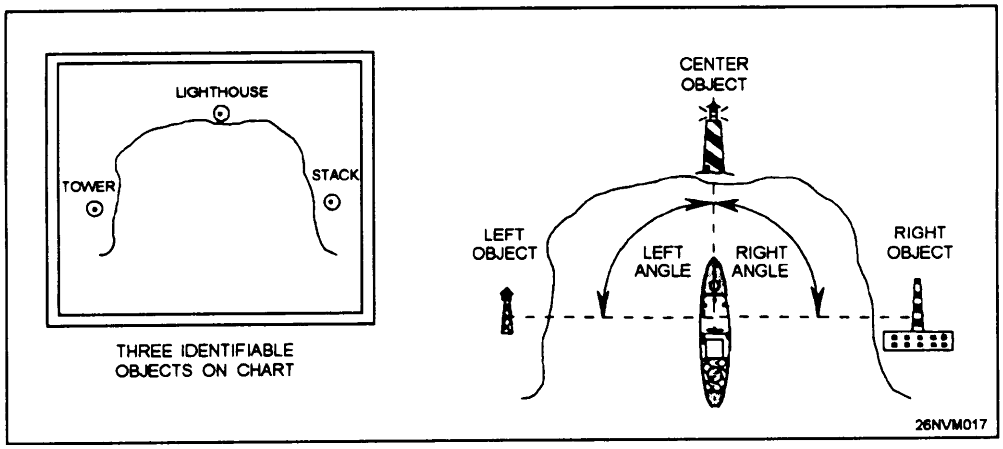


Figure 8-19. Select three objects to obtain two angles.

View of Two Objects

Figure 8-20 is an illustration of what you see when trying to determine the angle between two objects.

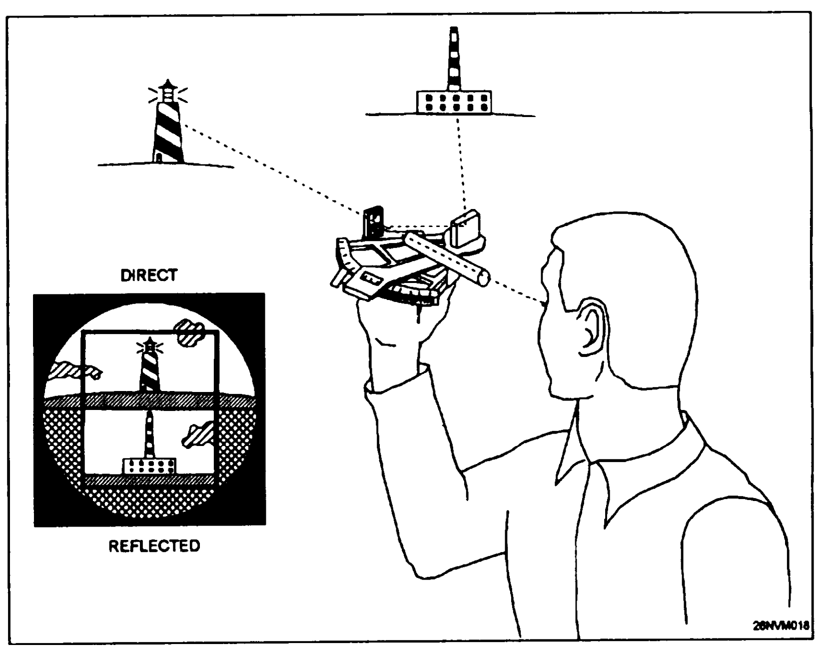


Figure 8-20. Horizontal measurement of two objects.

Using the Three-Arm Protractor

The two angles measured are plotted using a three-arm protractor. This instrument, made of brass or plastic, consists of a circular scale that can be read to fractions of a degree or minutes of arc, and to which the three arms are attached. The center, or index arm, is fixed and the zero graduation of the protractor coincides with the straightedge of this arm. The other arms are movable and can be set and locked at any angle relative to the fixed arm. Figure 8-21 is a diagram of a plastic three-arm protractor.

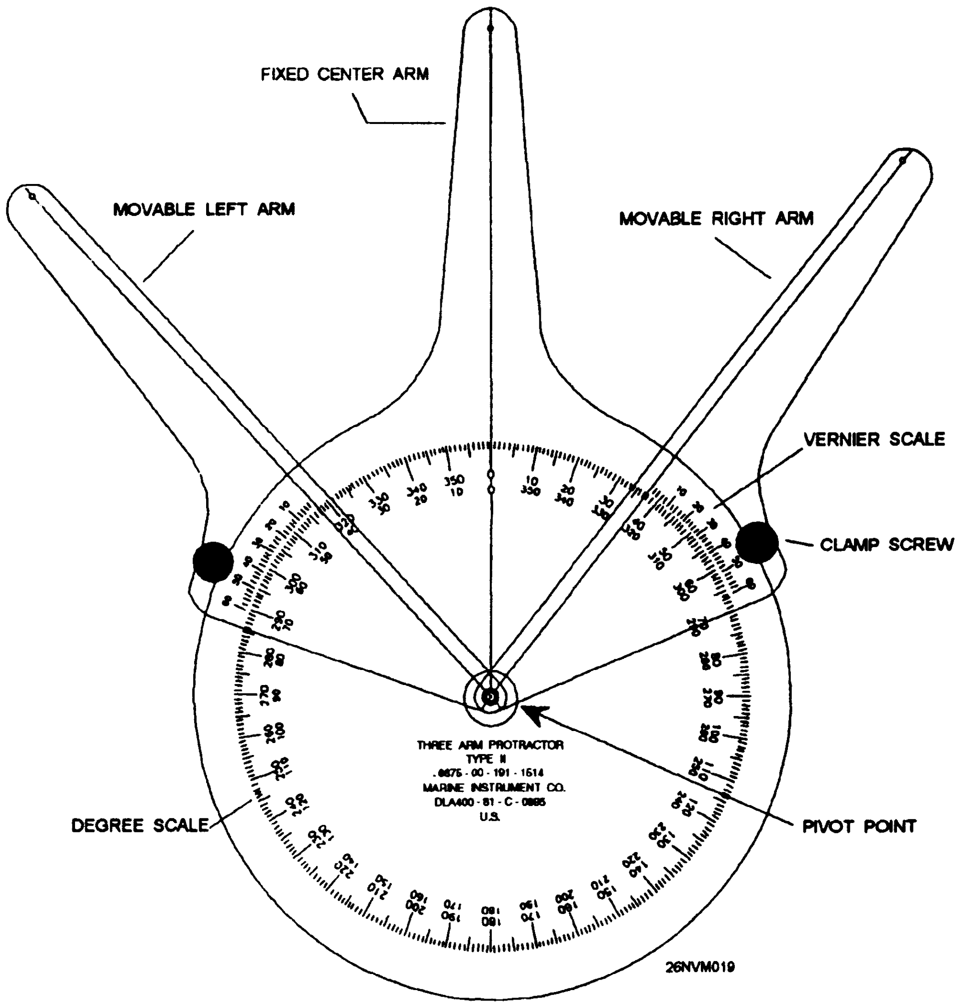


Figure 8-21. Plastic three-arm protractor.

Setting the Protractor

The movable arms can be set to the nearest minute of arc using the vernier scale that is inscribed on the movable arms. Use the following steps when setting the movable arms to a specific angle. Figure 8-22 is an example of a setting of 12° 18' on the three-arm protractor.

Step	Action
1.	Loosen the clam screw on the arm you are setting.
2.	Move the arm so that the index line is between the degree you want and the next higher degree.
3.	Adjust the arm so that the vernier mark indicating the minutes of arc you want is directly in line with the degree mark closest to it. **Note:** Make sure you apply the index error correction to angles.
4.	Tighten the clamp screw on the arm.
5.	Repeat steps 1 through 4 on the other arm for the second angle.

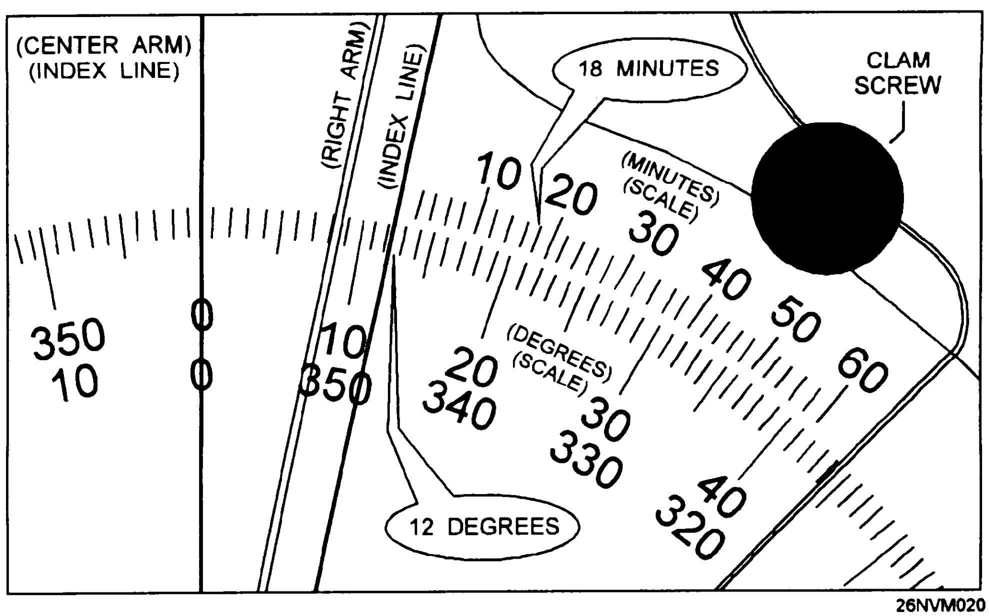


Figure 8-22. Setting angle on the three-arm protractor.

Obtaining the Fix

You must first observe the angles with a sextant and set the three-arm protractor with those angles.

Swingers or Revolvers

If the three objects and the ship all lie on the *circumference of a circle,* the fix is NOT reliable. When this happens, it is called a swinger or revolver and your ship could be anywhere along the circle and still have the same two angles to the three objects. See figure 8-23.

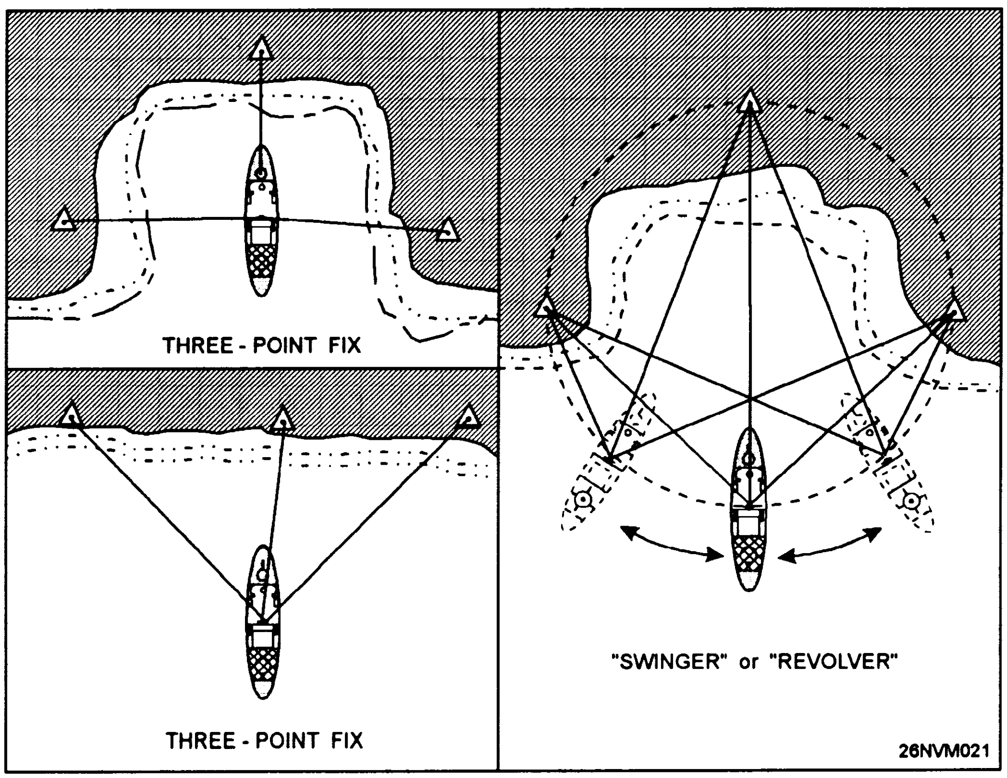


Figure 8-23. Difference between fixes and swingers.

Procedure for Plotting the Fix

Use the following steps when you are plotting a position using horizontal sextant angles. Figure 8-24 shows how the protractor is positioned to plot the horizontal sextant angles.

Step	Action
1.	Place the three-arm protractor on the chart.
2.	Position the center (fixed) index line so that it passes through the center object.
3.	Move the protractor slowly across the chart until all three arms are aligned with the three objects.
4.	Mark the ship's position on the chart by inserting a pencil point in the center of the protractor (pivot point).
5.	Check to see that the fix is not a swinger or revolver.

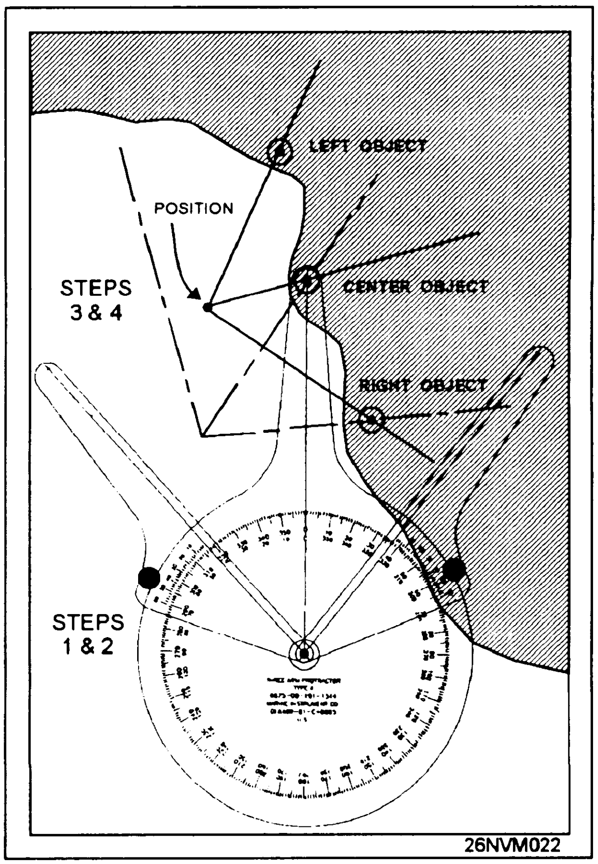


Figure 8-24. Aligning the three-am protractor.

Determining the Ship's Position by Running Fix

The Running Fix

Occasions will arise when it isn't possible to shoot three or more objects to fix the ship's position. In such instances, a single LOP shot on a single object can be advanced to a common time, resulting in a running fix. Advancing a LOP requires nothing more than moving the LOP forward on the same bearing as the ship's course and using the ship's speed without consideration of any current present.

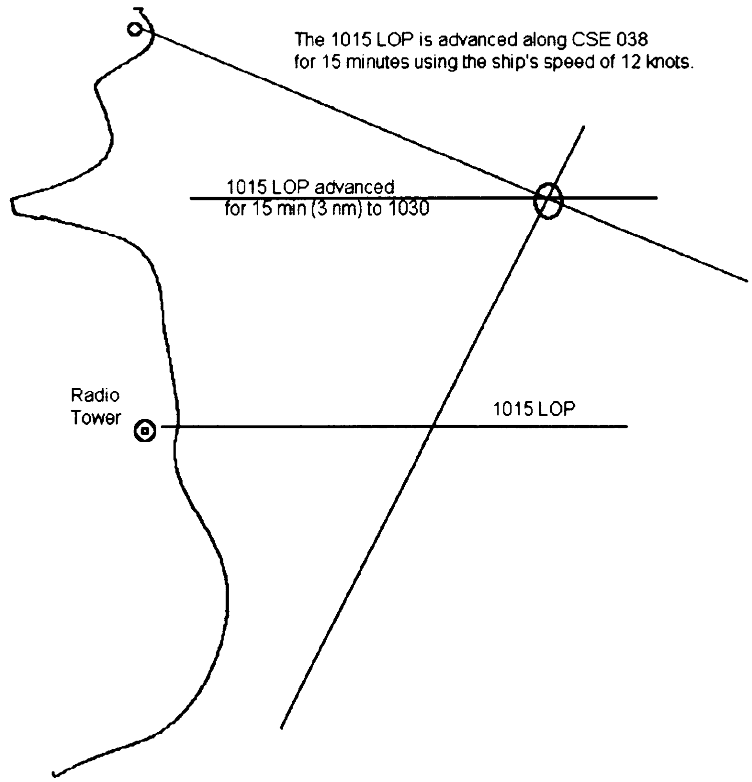


Figure 8-25. Advancing a LOP.

A running fix is labeled in the same manner as a visual fix except that the abbreviation R. fix is put beside the fix and fix time.

Figure 8-25 shows an example of how a LOP is advanced (moved) to obtain a running fix.

Electronic Navigation

Introduction

Position is determined in electronic navigation in about the same way that it is in piloting, but there is this important difference: the objects used to fix the ship's position need not be visible from the ship. Instead, their bearings (and sometimes their ranges) are obtained electronically.

There are many different types of electronic equipment used in navigation; some of these you may have used, others you may have only heard about. Some of the more important ones are:

- Fathometer
- Radar
- Loran-C
- RDF
- Omega
- SATNAV
- SINS
- GPS

Many people believe that electronic navigation is becoming a primary method for both piloting and long-range navigation. However, you must continually bear in mind that there is no one system that can always be used. Every method has its own limitations, and you should appreciate and understand them. Electronic methods are vulnerable because of the possibility of breakdown, malfunctioning, or damage. They are also subject to atmospheric conditions and some can be successfully blocked by jamming, capture, or destruction of related shore equipment by an opposing force. You must, therefore, have a working knowledge of all navigational methods available to you and be able to use them all as required. Furthermore, the old saying "the equipment is only as accurate as its operators" holds true. And operators are only as accurate as their complete knowledge of the equipment they are using.

Section Objectives

- Describe the procedure used to annotate the fathometer echogram.
- List the components of the fathometer.
- List at least five types of electronic equipment used in navigation.
- List the five steps used to plot time difference lines used occasionally with electronic navigation.
- List the components and operation of satellite navigation systems.

Using the Fathometer

Echo-sounding Equipment

Charted landmarks on the ocean floor are often useful in assisting mariners in determining their position. Submarine trenches, canyons, ridges, and seamounts can all be useful in navigation. Echo-sounding equipment such as the Navy AN/UQN-4 is the most common fathometer found on naval vessels. This fathometer is the most accurate for obtaining soundings in shallow depths. The AN/UQN-4 can be set for five different scales. It is equipped with a digital display for reading all scales and it has a strip chart recorder that actually traces the profile of the ocean bottom when reading the 600-foot, 600-fathom, or 6,000-fathom scale. The smallest possible scale should always be used. See figure 8-26.

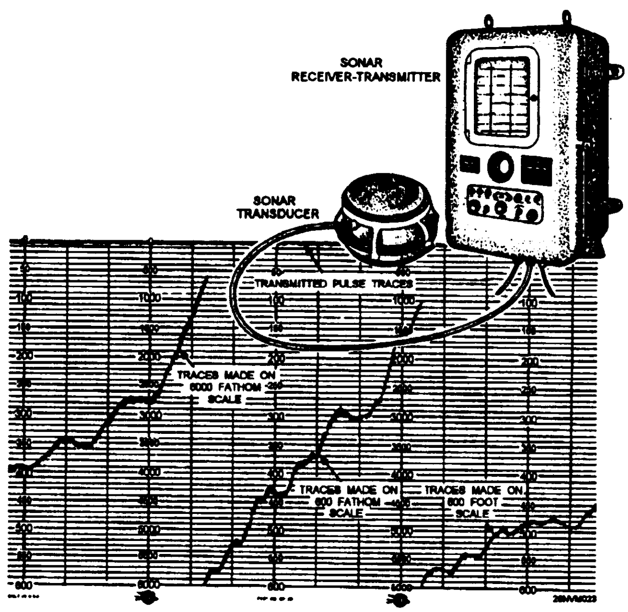


Figure 8-26. Fathometer, transducer, and echogram.

Annotating the Echogram

The paper on which the depths are recorded is used to annotate the following information at the times indicated:

- The ship’s name must be placed at the beginning and at the end of each roll of paper.
- Time in GMT must be marked at the beginning of each watch.
- The current date should be recorded each day at 1200.
- Time and date must also be marked whenever the unit is turned on.

LORAN-C

Introduction

Loran-C (**LO**ng **RA**nge **N**avigation) is an electronic aid to navigation consisting of shore-based radio transmitters. The Loran system enables users to determine their position quickly and accurately day or night in any weather. Your position is determined by locating the crossing point of two lines of position on a Loran-C chart. Most units today will give you a direct readout in latitude and longitude, which will allow you to plot your position even if you do not have a Loran overprinted chart. Loran-C is generally accurate to 1/4 nautical mile. The Loran-C system allows you to determine your position by means of radio signals broadcast by stations of known position. A fix is determined by Loran through the intersection of lines of position obtained by reference to shore stations whose locations are known.

Time Difference Lines

In Loran-C, you locate a LOP by determining the difference in time of arrival of signals sent out by each of a pair of broadcast stations. This interval is constant when the ship is located anywhere along a previously determined Loran-C LOP. To say it another way: When the time interval is a specific amount, the ship must be somewhere on a predetermined Loran-C LOP that is a focus of all points where the interval between arrival of signals is the same.

Plotting Time Difference Lines

Most of the Loran-C receivers in use today provide the user with two displays of fix information. The most commonly used is a readout of the latitude and longitude of the vessel’s position. The other is a readout of the time delay of each LOP, which can then be plotted on a Loran-C overprinted chart. The steps for plotting the time difference LOPS are described briefly below:

Step	Action
1.	Examine the Loran-C chart for your area. LOP lines are marked with time difference numbers; chain and secondary identification also appear every few lines.
2.	Read the time difference in the TDA display.
3.	On the chart, locate the line that most closely fits that reading for the secondary selected.
4.	Examine adjacent lines and interpolate to determine where the line that corresponds to your reading is to be plotted
5.	Repeat steps 2 and 3 for the TDB display
6.	Locate the point where the two lines cross and label the fix with a small triangle along with the time affixed close by.

Satellite Navigation Systems

SATNAV

The **SAT**ellite **NAV**igation (SATNAV) system is a highly accurate, passive, all-weather, worldwide navigational system suitable for subsurface and surface navigation, as well as for use in aircraft. This system has been in wide use in the fleet, and is also available to commercial interests. Because of today's technology and expertise in transistors, computers, and miniaturization, this system is extremely accurate.

SATNAV plotting is made simple because the receiver gives a written printout of the latitude and longitude of the vessel's position along with other information about the satellite pass which gives the navigator valuable information about the accuracy of that particular satellite pass and the time of the next pass. The AN-SRN-19 (fig. 8-27) is being replaced throughout the fleet by the WRN-6 GPS navigation system. Refer to the SRN-19 operators manual for specific instructions for system setup.

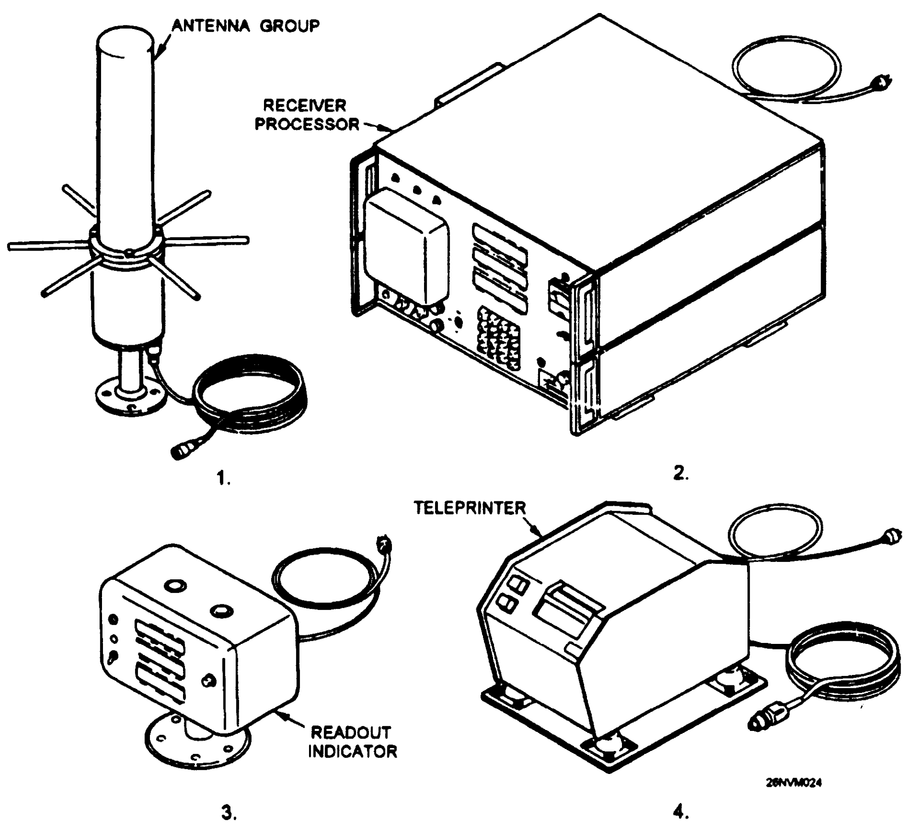


Figure 8-27. AN/MN-19 Satellite Navigation Set.

Navstar GPS

The Navstar **G**lobal **P**ositioning **S**ystem (GPS) was developed to provide highly precise position and time information anywhere in the world, regardless of weather conditions. Now fully operational, GPS consists of 21 satellites (plus 3 operational spares). See figure 8-28. The precise stationing of these satellites will provide worldwide coverage with a minimum of 4 satellites in view of any user.

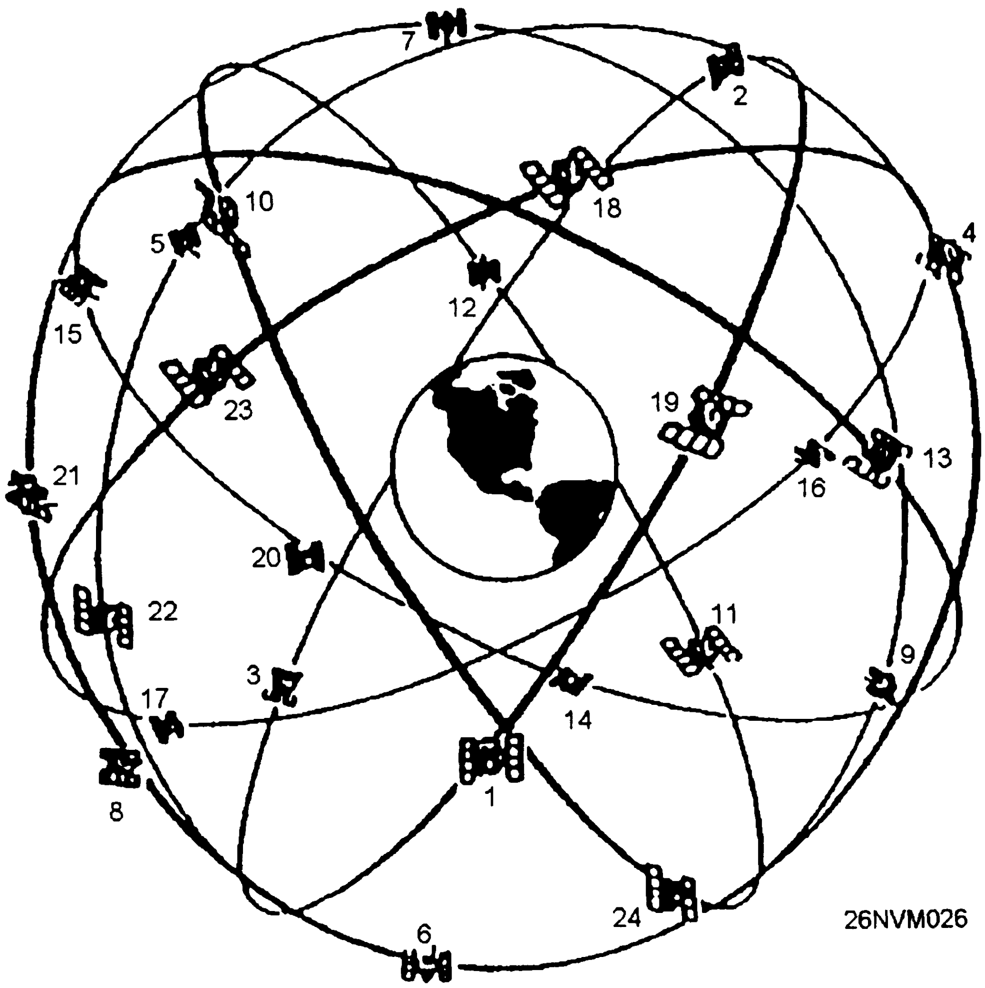


Figure 8-28. Navstar GPS Satellite Constellation.

GPS Signals

Figure 8-29 depicts a simplified view of how a GPS signal is processed. The AN/WRN-6 Satellite Signals Navigation Set is the receiver that the Navy uses to obtain and display GPS fixes.

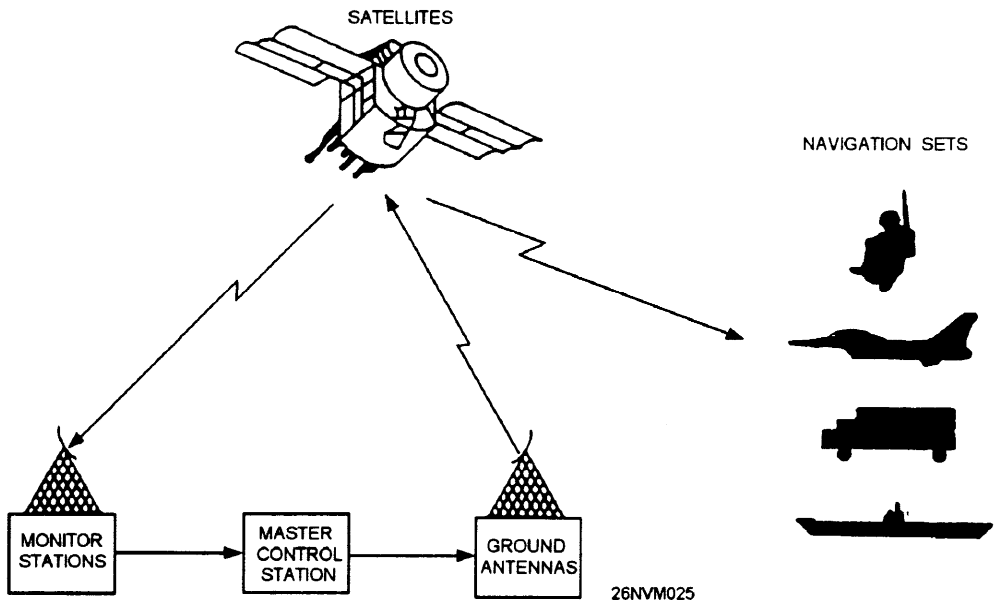


Figure 8-29. Navstar global positioning system.

AN/WRN 6(V)

The AN/WRN 6(V), shown in figure 8-30, computes accurate position coordinate, elevation, speed, and time information from the signals transmitted from GPS satellites.

Accuracy: The AN/WRN 6(V) will provide positions accurate within 100 meters in the unencrypted mode and positions accurate to within 16 meters or less in the encrypted mode. At all times, if possible, the AN/WRN 6(V) should be operated in the encrypted mode.

Operating Procedures: Specific operating instructions for the AN/WRN 6(V) are contained in NAVY SPAWAR publication EE170-AA-OMI-020/WRN6. All Quartermasters should become well versed in the contents of this publication.

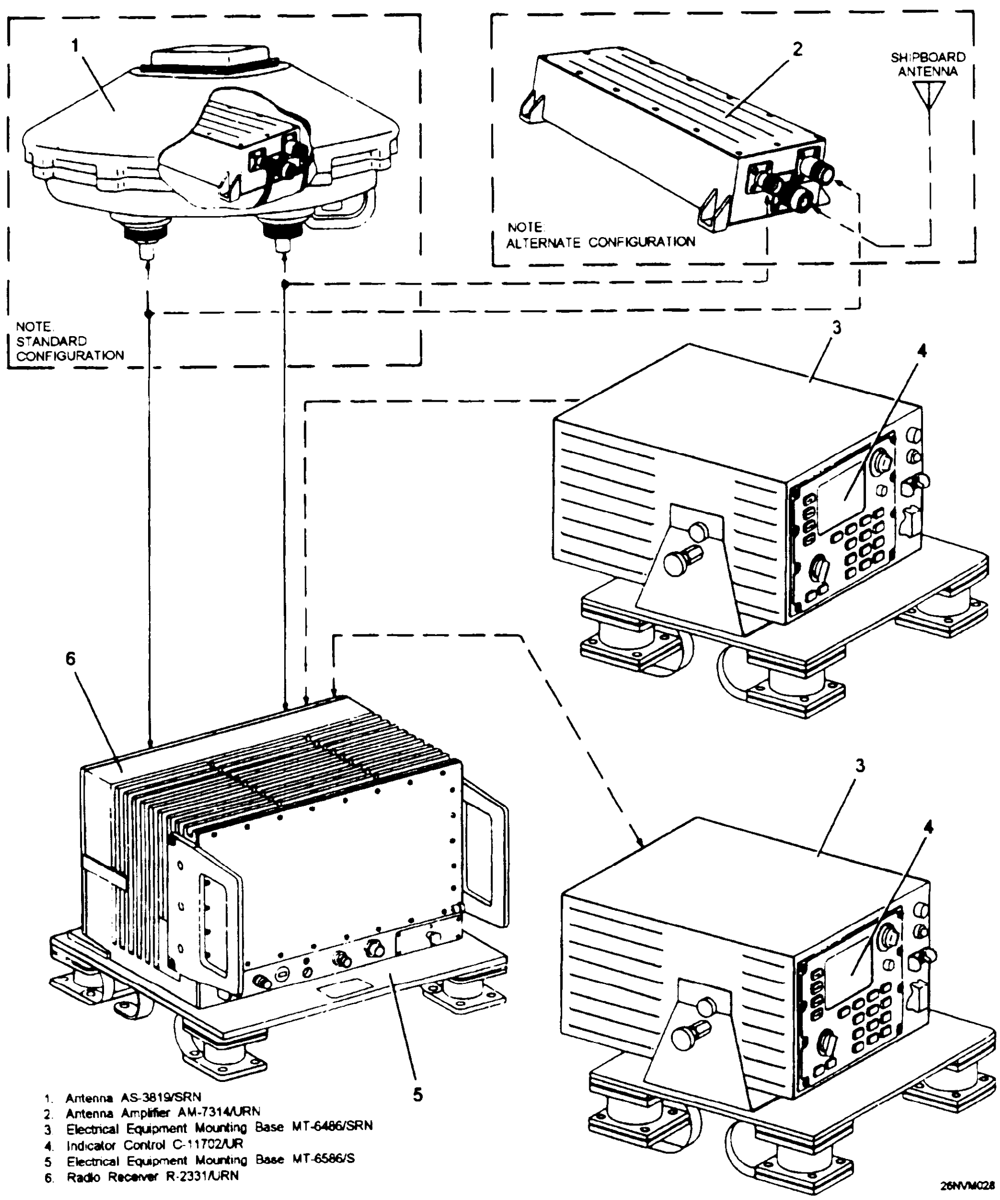


Figure 8-30. Satellite Signals Navigation Set AN/WRN 6(V).

Navigational Radar

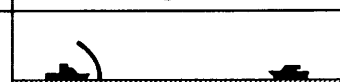
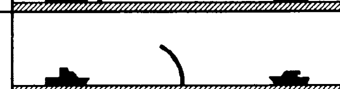
Components of RADAR

A typical surface radar set is made up of five components.

Component	Description of Function
Transmitter	Sends out electromagnetic waves of energy.
Modulator	Allows waves to be omitted as pulses.
Antenna	Beams the energy at the targets and rotates to scan the surrounding area.
Receiver	Converts the reflected radio energy returned from the target into usable data.
Indicator	Presents the data received visually on a scope.

How RADAR Works

The following stages help to explain how radar operates:

Stage	Description	Diagram
1	Pulse leaves radar antenna at the speed of light.	
2	Pulse continues through space.	
3	Pulse strikes target.	
4	Echo is returned as original pulse continues.	
5	Echo returned at speed of light.	
6	Echo received by antenna giving indication on scope of presence of other ship.	

26NVM029

Plan Position Indicator (PPI)

The PPI scope provides a bird's-eye view of the area covered by the radar with your ship in the center. The sweep appears as a bright line and originates in the center of the scope and extends to the outside edge. This straight line sweep is synchronized with the radar antenna and rotates 360°. Each time a target is detected, it appears as an intensified spot on the scope. See figure 8-31.

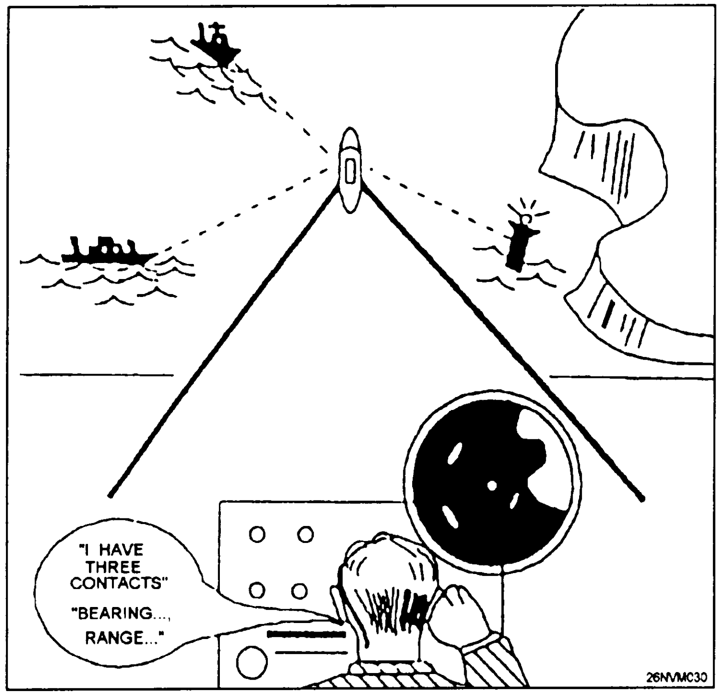


Figure 8-31. PPI presentation.

PPI Display Interpretation

The scope can be adjusted to several different range scales to provide greater target detail. Range is measured in yards or nautical miles from the center of the scope to the target indicated.

Some factors affecting the accuracy of radar are beam width, pulse length, mechanical adjustment, and interpretation. Because of beam width distortion, radar bearings are usually less accurate than radar ranges. A fix obtained where two or more lines of position are determined by ranges is more accurate than one obtained by bearings alone. In most cases, radar ranges will always be available and will be used over radar bearings.

Shorelines appear as they do on the chart; however, the PPI displays a scaled down version of an area of the chart. Determining exactly what you are seeing and where that area is on the chart takes practice.

How to Obtain a RADAR Bearing and Range

Bearings

The PPI is equipped with a *bearing cursor* and a *range strobe.* The bearing cursor, like the sweep, appears as a bright line and can be manually rotated through 360°. Bearing information is obtained by rotating the cursor to the center of the target. The target bearing is then read directly from the bearing dial. On gyro-equipped ships (and most ships having radars are so equipped), the radar has a gyro input and bearings obtained from it are true. If a gyro failure occurs the radar presentation automatically re-orients to a relative picture and relative bearings may be taken from the PPI.

Ranges

The range strobe appears as a bright spot riding on the cursor. As the range crank is turned clockwise, the strobe moves out from the center. Range is obtained by placing the strobe on the leading edge (edge closest to the center of the PPI) of the target. The target range is then read directly from the range dials, either in miles or yards.

Selecting Objects to Shoot

When plotting a radar fix, you will have already been comparing your radar "picture" with the navigational chart. Pick out points that show *prominently* on both the chart and the radar. Try to locate reliable targets that are easy to identify. You cannot afford to guess on what you are using to obtain a range from. Objects not permanently fixed to shore or the ocean bottom such as buoys should not be used when obtaining a radar fix. Tangents also should be used as a last resort.

Shooting Ranges in Proper Order

The order in which you take your radar ranges is just as important as it was in visual bearings. Take radar ranges ahead and astern first because they are changing most rapidly, then take ranges on or near the beam. As is true with visual fixes, time is a critical element. Work quickly, but accurately.

How to Plot RADAR Fixes

Procedure

Use the following steps to properly plot a radar fix. Figure 8-32 is an illustration of what a fix using three radar ranges looks like.

Step	Action
1.	Locate the distance scales or the latitude scale near your approximate location on the chart.
2.	Measure the distance on the scale using a compass.
3.	Locate the charted navigational point used for the range.
4.	Place the sharp point of the compass on the chart where you took the range and draw an arc in the vicinity of your DR position.
5.	Repeat steps 2 thru 4 for all the ranges obtained.
6.	Locate the area where the lines of position (arcs) all cross each other.
7.	Label the radar fix by putting a small triangle around the intersection of the ranges, with the time of the fix noted close to the symbol.

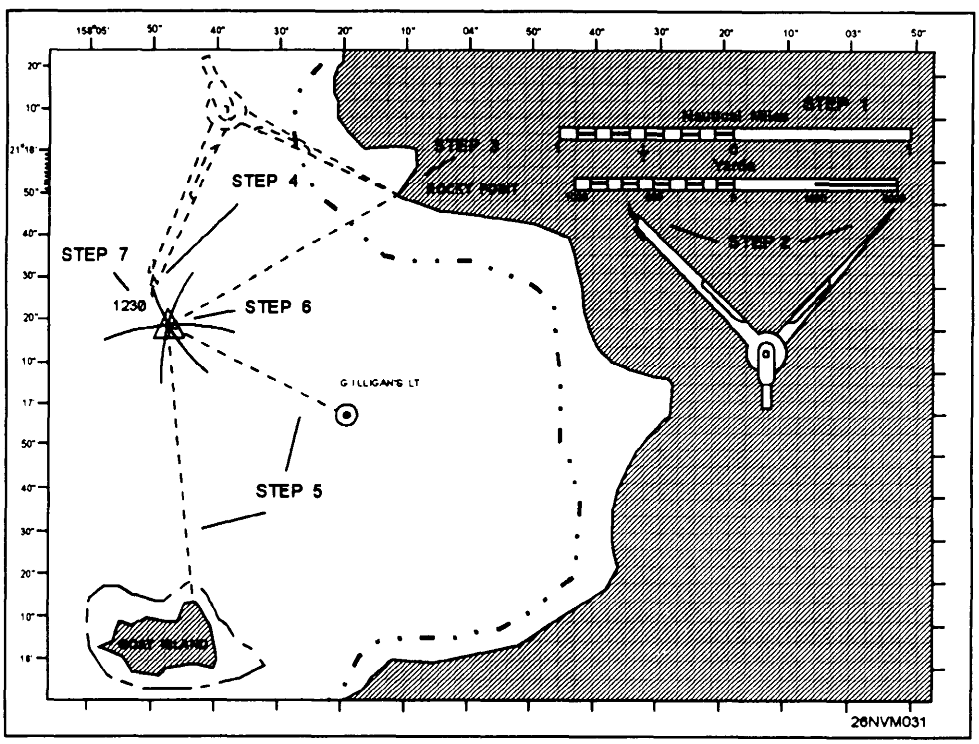


Figure 8-32. Example of a radar fix.

Other Electronic Navigation Equipment

SINS

SINS (**S**hip's **I**nertial **N**avigation **S**ystem) is the process of directing the movements of a rocket, ship, aircraft, or other vehicle from one point to another, based on sensing acceleration of the vehicle in a known spatial direction with the aid of instruments that mechanize the Newtonian laws of motion, and integrating acceleration to determine velocity and position.

SINS is an accurate, all-weather, dead reckoning system. It employs gyroscopes, accelerometers, and associated electronics to sense turning rates and accelerations associated with the rotation of the Earth, and with ship's movement relative to the surface of the Earth.

Radio Direction Finders

Radio beacons were the first electronic aid to navigation. The basic value of the radio beacon system lies in its simplicity of operation and its relatively low user costs, even though the results obtained may be somewhat limited. The **R**adio **D**irection **F**inder (RDF) is a specially designed radio receiver equipped with a directional antenna. The antenna is used to determine the direction of the signal emitted by a, shore station, relative to the vessel. A radio beacon is basically a short-range navigational aid, with ranges from 10 to 175 nautical miles. Bearings can be obtained at greater ranges, but they are usually of doubtful accuracy and should be used with caution. When the distance to a radio beacon is greater than 50 miles, a correction is usually applied to the bearing before plotting on a Mercator chart. These corrections, as well as information on the accuracy of bearings, plotting, and other matters, are contained in DMA publication 117, Radio Navigational Aids.